A New Active Polyphase Filter for Image Rejection Using Second Generation Current Conveyors

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Abstract **In RF receivers, many interferers accompany the desired signal in its entrance to the front end of the receiver. Of particular interest out of these interferes is the image, which if downconverted with the desired signal by the same local oscillator, severely corrupts the received information. In low IF receivers, the image can only be eliminated after the downconversion by several means, one of which is using a polyphase filter. This paper discusses available current solutions and then introduces a new low power high dynamic range polyphase filter built with the commercially available Plus-Type Second Generation Current Conveyors (CCII+). SPICE simulation results show that image rejection of 15dBs can be achieved using only one stage of this filter.**

Key Words: Polyphase filters, current conveyors, complex filters, image rejection.

I. INTRODUCTION

While no image exists in direct conversion receivers, because the incoming signal is transmitted directly to the baseband, heterodyne and low-IF receivers suffer from the image problem. In heterodyne receivers the image is commonly suppressed before down conversion using high Q Surface Acoustic Wave (SAW) filters. However, in low IF receivers the image is suppressed after the down conversion. That is because the IF is low and as a result the image and the desired signal frequencies would be very near. Rejecting the image frequency before down conversion requires unrealistically high Q image reject filter.

Two popular image rejection architecture designs were introduced by Hartley [1] and Weaver [2]. Hartley's circuit mixes the RF input with the quadrature phases of the local oscillator, low pass filters the resulting signals, and shifts one by 90° before adding them together. Following the full analysis in [3], the principle of operation is that, after the 90° phase shift the desired signal in both quadrature paths will have the same polarity while the image signal will have opposite polarity in one of the phases with respect to the other. Hence when added, the desired signal will add up while the image will be cancelled. The principle drawback of Hartley's architecture is its sensitivity to mismatches [3]. If the LO phases are not in exact quadrature or the gains and phase shifts of both quadrature paths (the filters and the phase shifter) are not identical, then the image cancellation will be incomplete and the image will corrupt the desired downconverted signal.

Weaver architecture [2] is very similar to Hartley's architecture except that it replaces Hartley's 90° phase shift stage by a second quadrature stage to perform essentially the same function. Like Hartley's architecture, Weaver architecture also suffers from the incomplete image cancellation due to the mismatch problem. But while Weaver architecture does not suffer from the gain mismatch from the 90° phase shift operation as in Hartley's architecture, it suffers from another problem that is the second image if the second downconversion translates the spectrum to a non-zero frequency.

A better approach is to replace the two filters in both the quadrature paths and the phase shift phases by a single polyphase filter, in which case there would be no mismatch problems and better Image Rejection Ratio (IRR) can be achieved. The general concept is; because the desired signal and the image appear in two opposite frequency polarities after down conversion, a circuit must be designed that is able to distinguish between positive and negative frequencies, hence pass the positive, that is the desired signal, and suppress the negative, that is the image interferer.

II. POLYPHASE FILTERS

An image-rejecting I/Q mixer delivers two outputs in quadrature in such a way that if the first output's phase lags behind the second output's phase by 90° for the desired signal, then the first output's phase leads the second output's phase by 90° for the image signal [4]. An image reject mixer would be preceding a polyphase filter the response of which depends on the phase difference between its two input signals. That is, it has passband response for the target signal and an attenuating response for the image signal.

There are several advantages of using a polyphase filter instead the two separate filters solution [4]. First, for the same degree of image suppression, the matching of the polyphase filter's components is less strict than the required matching in the case of two separate IF filters solution. This advantage arises due to the polyphase filter's close cross-coupling between the two quadrature paths of the RF receivers.

Also, having that in low-IF receivers, the data bandwidth is a significant fraction of the IF filter's centre frequency, it follows that the IF filter must have low Q. Typically, the frequency response of conventional low Q band pass filters is not symmetrical around the passband's centre frequency, and this distorts the received data's eye diagram. Hence a second advantage of the polyphase filter is that its bandpass response is symmetrical around the passband's centre frequency independent of its Q which keeps the data's eye diagram intact.

Polyphase filters can be either passive or active. Passive polyphase filters are built of only resistors and capacitors as [5] and [6]. Active polyphase filters consist of gain blocks with resistors and capacitors. One of the main advantages of active over passive polyphase filters is that active polyphase filters are more suitable for monolithic integration than their passive counterparts [4]. One more advantage of active over passive polyphase filters is that, in a receiver, a small wanted signal can be surrounded by large neighboring signals and this requires a very high dynamic range at the input, and such high levels of dynamic ranges can only be achieved using an active RC technique [7].

III. COMPLEX POLYPHASE FILTERS FOR IMAGE REJECTION

A low pass filter's transfer function can be written as [8],

$$H_{lp}(j\omega) = \frac{1}{1 + j\omega/\omega_o} \tag{1}$$

where ω_o is the cutoff frequency.

An active image rejection polyphase filter would have two fully differential I and Q inputs and two fully differential I and Q outputs. Hence the filter is governed by a set of four transfer functions from every input to every output. To perform image rejection in a low IF receiver, the filter must have a passband from positive to positive frequencies, an attenuation from negative to negative frequencies and no signal transfer from positive to negative or negative to positive frequencies. The transfer function and circuit synthesis of such a filter can be found by performing a linear frequency transformation on the low pass filter characteristic of equation (1) which guarantees that the resultant band pass transfer function will be different for positive and negative frequencies [8], so the band pass transfer function would be,

$$H_{bp}(j\omega) = \frac{1}{1 + (j\omega - j\omega_c)/\omega_o} \tag{2}$$

Working on the centre frequency of the filter and taking $\omega = +\omega_c$ (for the desired signal) the response of the filter is,

$$H_{bp}(j\omega) = \frac{1}{1 + (j\omega_c - j\omega_c)/\omega_o} \tag{3}$$

Therefore,

$$\left|H_{bp}\right| = 1 \tag{4}$$

While when $\omega = -\omega c$ (for the image) the response of the filter would be,

$$H_{bp}(j\omega) = \frac{1}{1 + (-j\omega_c - j\omega_c)/\omega_o} = \frac{1}{1 + (-2j\omega_c)/\omega_o} \tag{5}$$

Therefore,

$$\left|H_{bp}\right| = \frac{1}{\sqrt{1 + 4\left(\frac{\omega_c}{\omega_o}\right)^2}} \tag{6}$$

From equations (4) and (6) it is clear that the magnitude of the response will be much lower when $\omega = -\omega_c$ (Image) than when $\omega = +\omega_c$ (signal). From this mathematical analysis it can be shown that this bandpass filter's transfer function will have a passband response for the desired signal and an attenuation for the image signal, hence can be used for image rejection.

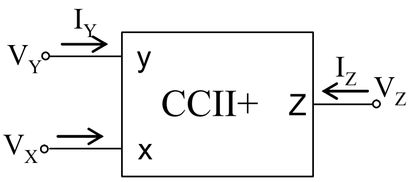
In [8] an active realisation of this transfer function was presented using two operational amplifiers, resistors and capacitors. Operational amplifiers are voltage mode devices and require relatively large supply voltages and thus consuming relatively high power. Moreover, limited slew rates, and limited gain-bandwidth products will limit the high frequency performance of operational amplifier-based circuits.

IV. PROPOSED NEW SOLUTION (CCII+ BASED POLYPHASE FILTER)

Current mode devices such as the Plus-Type Second Generation Current Conveyor (CCII+) have many advantages over voltage mode devices such as the operational amplifier. These advantages are in terms of inherently wide bandwidth, greater linearity, wide dynamic range, simple circuitry and lower power consumption [9].

These properties appropriately fit with the ever lasting efforts of improvements to RF front ends in terms of both performance quality and power consumption. Wide dynamic range is required at the input of the filter due to the large neighboring signals that could be surrounding the desired signal as previously stated. Simple circuitry leads to less design time and easier implementation, hence cheaper products while greater linearity leads to better circuit performance and higher power efficiency which is much needed to cope with the increasing demand for smaller and non power hungry devices in the wireless market.

Figure 1 shows a symbol representation of the current conveyor and its transfer function while figure 2 shows the new active polyphase filter built completely using CCII+, resistors and capacitors.



$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \end{bmatrix}$$

Figure 1. Symbol representation of CCII+ and its transfer function

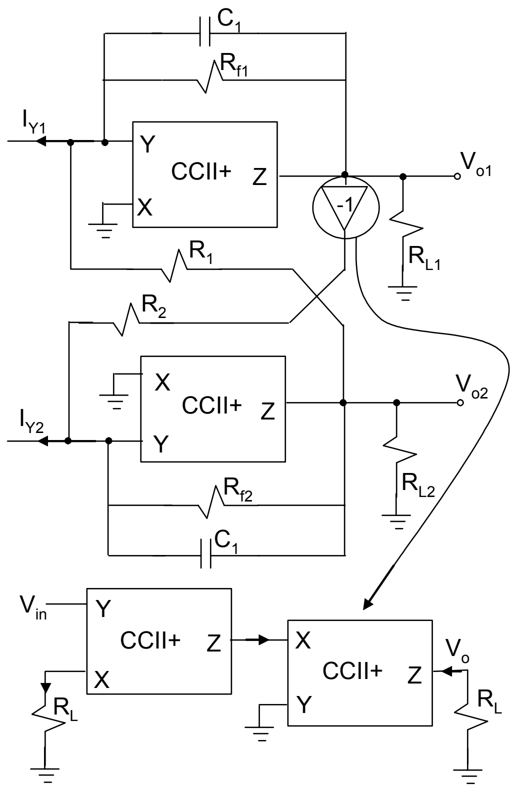


Figure 2. The proposed active polyphase filter using CCII+

The principle of operation of both this circuit and the circuit presented in [7] can be found by voltage and current analysis of the simplified version presented in [4] as shown in Figure 3.

Routine analysis of the above circuit yields,

$$i_{c1} = j\omega C_1 v_{o1}\,,\ i_{f1} = \frac{1}{R_{f1}} v_{o1} \text{ and } i_{R1} = \frac{1}{R_1} v_{o2}$$

Therefore,

$$i_{i1} - j\omega C_1 v_{o1} - \frac{1}{R_{f1}} v_{o1} - \frac{1}{R_1} v_{o2} = 0 \tag{6}$$

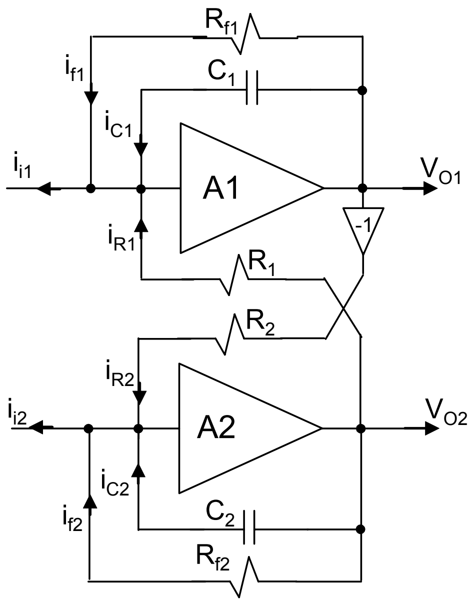


Figure 3. Simple active polyphase filter for analysis

Since the filter's outputs are in quadrature,

$$v_{o1} = j v_{o2}$$

then equation (6) can be rewritten as

$$i_{i1} - j\omega C_1 v_{o1} - \frac{1}{R_{f1}} v_{o1} + j\frac{1}{R_1} v_{o2} = 0 \tag{7}$$

Rearranging (7) yields,

$$\frac{v_{o1}}{i_{i1}} = \frac{R_{f1}}{1 + j\left(\omega C_1 R_{f1} - \dfrac{C_1 R_{f1}}{C_1 R_1}\right)} \tag{8}$$

or,

$$\frac{v_{o1}}{i_{i1}} = \frac{R_{f1}}{1 + j\left(\dfrac{\omega}{\omega_o} - \dfrac{\omega_C}{\omega_o}\right)} \tag{9}$$

where $\omega_o = 1/C_1R_{f1}$ and $\omega_C = 1/C_1R_1$. Thus the bandpass filter transfer function of equation (2) is realized.

For these equations to apply, the input voltage of the gain block and the current into the gain block must be zero. In the proposed CCII+ circuit this has been achieved by connecting one of the terminals of the CCII+ to ground. Due to the characteristics of the CCII+ the two input voltages will be forced to be equal, hence if one is connected to ground, the other will be forced to zero as well. Moreover, the y-input of the CCII+ was used as the input of the gain block. With y-input current equal to zero, the current into the gain block will be zero, and the same set of equations can apply.

V. RESULTS

This circuit was successfully simulated using SPICE. The CCII+ was simulated using the commercially available AD844 model. Figure shows the simulation results. These results were obtained by running the simulation twice. First inputs were applied such that the I input would be leading Q input and the response of the filter was produced. The phase difference was then reversed in the second run with the I input lagging the Q input by 90 degrees as would happen with an image. The results clearly show how the response of the filter will change with the phase reverse which therefore demonstrates that it can be used for image rejection. Since the level of image rejection here is about 15dB, four stages of this filter would be required to achieve the 60dB image rejection usually required in low-IF receivers.

VI. CONCLUSION

This paper contributed a new innovation to add to the ongoing efforts of improving image rejection techniques. The circuit presented is the first current mode active image reject poly phase filter and was designed utilizing the properties of the current conveyor. This is expected to improve the circuit performance in terms of higher frequencies of operation and power consumption, hence open wide doors for possible future conversion from voltage mode to current mode circuits where the advantages of current mode to voltage mode circuits is found evident. The circuit simulation obtained about 15 dB of image rejection which is relatively good at a frequency of the order of few MHz for only one stage of filter. Future development to this circuit would look at possible improvements in the programmability of the filter such that it can be used in multi frequency communication systems.

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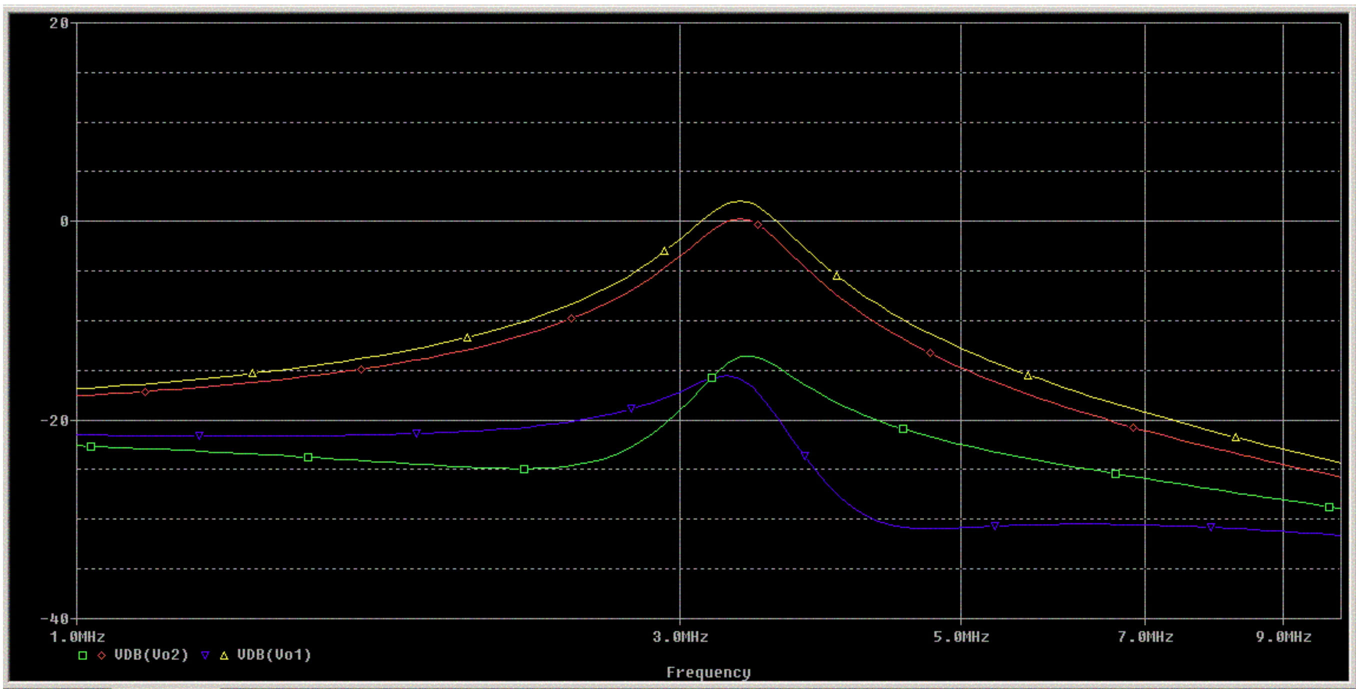

Fig. 4 The gain-frequency characteristics of the polyphase filter realization of Fig. 2