Active Impedance Inverter: Analysis and its Application to the Bandpass Filter Design

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Abstract — **In this paper the analytical approach to the realizability of the active inverters is described and a very stable active inverter using the conventional feedback network is also proposed. Based on the proposed analysis method active bandpass filters are designed and built at 850 MHz. Measured results of two and three pole bandpass filters are presented as well as the theoretical results.**

I. Introduction

RF active bandpass filters have been reported by several authors[1]-[9], based on active resonators, active inverters and other schemes. The active resonators made of either active inductors or active capacitors may introduce instability in the filter circuit, because in order to compensate the loss from the resistance component of the resonators the negative resistance characteristics are involved. The active inverters are known to introduce less instability than the active resonators do. However, the functional description of the active inverter blocks in the filters has not been thoroughly studied. In this paper, the theoretical analysis of the active impedance inverter block for the bandpass filter is presented. In general, the active devices such as BJTs and MESFETs have different input and output impedance levels, while the passive inverters have the same values in nature. In order to adjust the impedance levels of active inverters, we applied the feedback to the active circuits. Based on the theoretical analysis we designed and tested several bandpass filters.

II. Analysis of Active Impedance Inverter

General way to design RF filters is to use the impedance(or admittance) inverters. Passive impedance inverters is well defined and widely used. The active inverter block can be described as shown in Fig. 1 where the active device is represented as scattering matrix S. The input impedance of the block in Fig. 1 can be

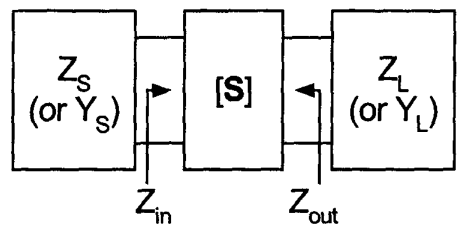

Fig. 1. The configurations of active impedance inverters with arbitrary impedance level

written as

$$Z_{in} = f_{in}(Z_L, \mathrm{S}) \tag{1-a}$$

where the function f_{in} is expressed in terms of the scattering parameters, S, of the active device as well as the load impedance Z_L. The output impedance can be written in the similar manner as

$$Z_{out} = f_{out}(Z_S, \mathrm{S}) \tag{1-b}$$

where Z_S represents the source impedance. If the network is to work as an ideal impedance inverter, the input /output impedances are expressed by

$$Z_{in/out} = f_{in/out}(\mathrm{S})\frac{1}{Z_{L/S}} \tag{2}$$

By substituting scattering parameters into the eq. (2) one can derive the following equation:

$$Z_{in/out} = \frac{(1+S_{11}-S_{22}-\Delta)Z_{L/S} + (1+S_{11}+S_{22}+\Delta)Z_0}{(1-S_{11}-S_{22}+\Delta)Z_{L/S} + (1-S_{11}+S_{22}-\Delta)Z_0} \cdot Z_0 \tag{3}$$

where $\Delta = S_{11} \cdot S_{22} - S_{12} \cdot S_{21}$

The eq. (3) can be expressed as eq. (2) if the following conditions are met:

$$1+S_{11}-S_{22}-\Delta = 0, \tag{4}$$

and

$$1-S_{11}+S_{22}-\Delta = 0. \tag{5}$$

The resulting equation are derived as

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$$Z_{in/out} = \left(\frac{1+S_{11}+S_{22}+\Delta}{1-S_{11}-S_{22}+\Delta} \cdot Z_0^2 \right) \frac{1}{Z_{L/S}} = K^2 \frac{1}{Z_{L/S}} \tag{6}$$

and the impedance/admittance inverter is expressed by

$$K = \sqrt{\left(\frac{1+S_{11}+S_{22}+\Delta}{1-S_{11}-S_{22}+\Delta} \cdot Z_0^2 \right)} = \frac{1}{J}. \tag{7}$$

However, if eq.'s (4) and (5) are satisfied in the network in Fig. 1, one cannot expect the stable operation of the active device.

In order to avoid the possible instability, consider a different condition given as

$$S_{11} - S_{22} = 0. \tag{8}$$

Since the active devices have nonreciprocal properties, the values of the impedance inverters should be defined differently. In Fig. 2 we define the inverter values of active inverter at the input and output ports of the device as K_f and K_b, respectively, using eq. (3) as

$$K_f = \sqrt{\frac{(1-\Delta)Z_L + (1+S_{11}+S_{22}+\Delta)Z_0}{(1-S_{11}-S_{22}+\Delta)Z_L + (1-\Delta)Z_0} \cdot Z_0 \cdot Z_L} \tag{9-a}$$

$$K_b = \sqrt{\frac{(1-\Delta)Z_S + (1+S_{11}+S_{22}+\Delta)Z_0}{(1-S_{11}-S_{22}+\Delta)Z_S + (1-\Delta)Z_0} \cdot Z_0 \cdot Z_S} \tag{9-b}$$

where K_f represents the inverter value in the forward transmission, while K_b represents that in the reverse transmission. The admittance inverter values are written as

$$J_f = 1/K_f, \tag{10-a}$$

$$J_b = 1/K_b. \tag{10-b}$$

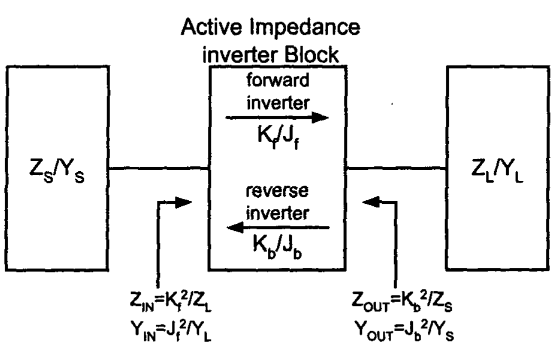

Fig. 2. The definitions of forward/reverse inverter

In practice the values of impedance/admittance inverters must be the same at both input and output ports. From the eq. (9-a) and (9-b), one can find the same value of forward and reverse inverters, if $Z_S = Z_L$ under the condition given by (8).

In order to meet the conditions given in eq. (8) and (9), consider an active inverter employing a feedback as shown in Fig. 3.

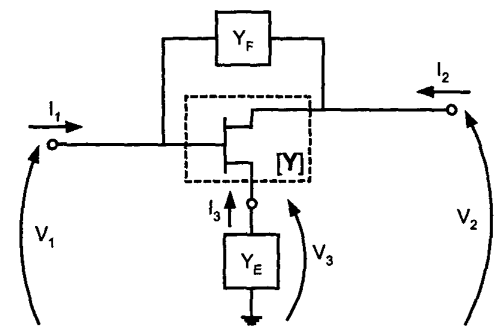

Fig. 3. Impedance inverter using feedback networks

By using y-parameters, the input/output impedances of the network in Fig. 4 are calculated as follows[10],

$$Z_{in} = \frac{(Y_F + Y_L)(\beta + Y_E) + (Y_E y_{22} + \Delta_y)}{(Y_E + Y_L)(\Delta_y + \beta Y_F) + Y_E Y_L (Y_F + y_{11})} \tag{11-a}$$

$$Z_{out} = \frac{(Y_F + Y_S)(\beta + Y_E) + (Y_E y_{11} + \Delta_y)}{(Y_E + Y_S)(\Delta_y + \beta Y_F) + Y_E Y_S (Y_F + y_{22})} \tag{11-b}$$

where $\beta = y_{11} + y_{12} + y_{21} + y_{22}$ (12)

and $\Delta_y = y_{11}y_{22} - y_{12}y_{21}$ (13)

As mentioned before, the active device has different impedances at the input and output ports. This means that $y_{11} \neq y_{22}$ and $Z_{in} \neq Z_{out}$ as shown in the eq. (11-a) and (11-b). However, the input and output impedances of the overall network in Fig. 3 can be adjusted by the amount of feedback. In general, the more amount of feedback is imposed, the closer values of input and output impedances are obtained. Therefore, using the feedback networks, we can design the active impedance inverter of which the value can be adjusted by the feedback network.

IV. Design of Bandpass Filters

The bandpass filter configuration is a cascaded network of resonators and inverters. The inverters can be either active or passive inverters. The design procedure starts with classical design method, such as Chebyshev type. Then the passive inverters are substituted for active inverters as shown in Fig. 4. The active devices with feedback networks have variable inverter values and input and output impedances depending on the amount of feedback. The active inverter in the Fig. 4 has the almost same impedance levels at both input and output ports. And its forward/reverse inverter values are adjusted to the passive inverter value.

Fig. 5 shows the designed active filter with two resonators in which chip inductors and capacitors are used. The filter configuration can be extended to the higher order by additional resonators and active, or passive inverters. In such case, the filter design procedure is similar as stated above.

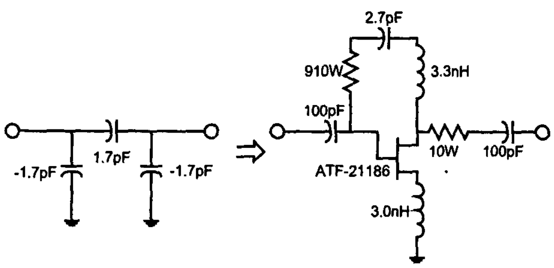

Fig. 4. Substitution of active inverter for passive one

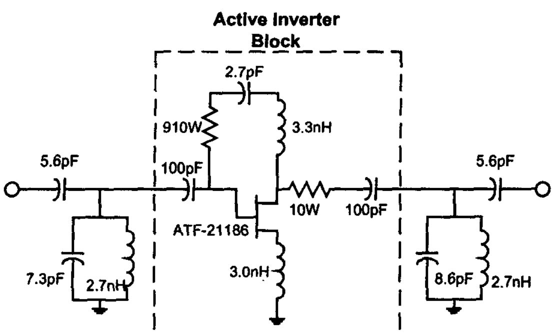

Fig. 5. The 2-pole active filter with an active impedance inverter

V. EXPERIMENTAL RESULTS

Two active filters having a center frequency of 865MHz were designed and tested. As FET devices, Agilent ATF-21186 MESFET's were used. A designed 2-pole bandpass filter has its insertion gain of 7.5dB at the center frequency of 900MHz with 180MHz bandwidth. The noise figure of the active bandpass filter is less than 2.8dB within its passband. A 3-pole bandpass filter has also been designed for cellular system application. This filter has its insertion gain of 24dB at the center frequency of 875MHz with 60MHz bandwidth. The noise figure is 2.5dB within its passband. In Fig. 6 and 7 we present the wideband characteristics of the two filters in order to show their stable operation over a wideband.

Filter	NF[dB]	Gain[dB]
2-pole filter	2.8	7.5
3-pole filter	2.5	24.4

Table I. Measured NF and Gain at 850MHz.

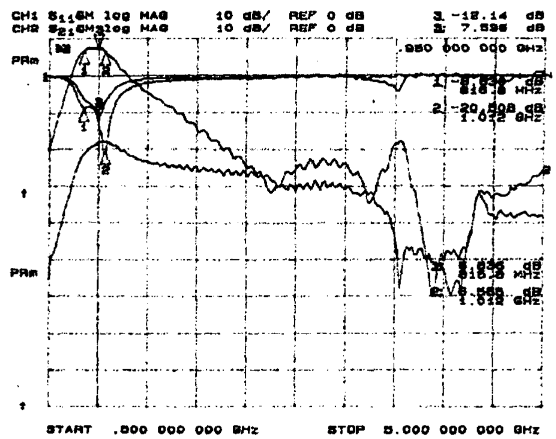

Fig. 6. Measured result of a 2-pole active filter

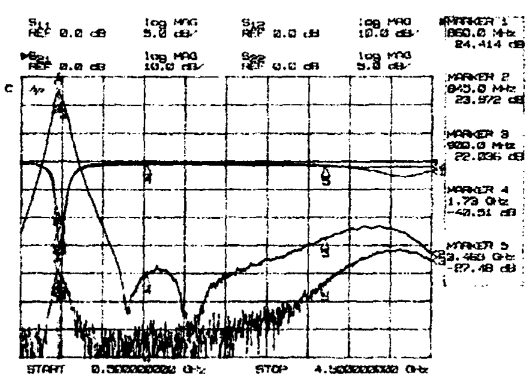

Fig. 7. Measured result of a 3-pole active filter

VI. CONCLUSION

The active impedance/admittance inverter has been described theoretically and its properties have been analyzed. The feedback network is found to be very useful because it provides not only stable operation of the active filters but also the degree of freedom in the inverter design. The designed active bandpass filters show as good results as the conventional passive filters.

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