Improvement of Gain Compression in Microwave Lumped and Transversal Bandpass Filters

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Abstract **— A new gain compression improvement technique for the microwave lumped and transversal bandpass filter is proposed in this paper. This technique uses active feedback for linearization of the main transversal element allowing an overall filter's *P1dB* elevation. In order to verify the proposed method, a prototype L-band microwave lumped and transversal bandpass filter with 2 GHz center frequency and 15% FBW is designed and fabricated. The experimental result exhibits an overall noise figure of 4.4 dB and reports a 6.5 dB *P1dB* improvement of the proposed filter when compared with a conventional structure.**

Index Terms **— Active feedback, Lumped and transversal filter, Gain compression.**

I. INTRODUCTION

Presently, modern communication transceivers require compact and highly selective microwave bandpass filters. These filters are usually implemented with passive elements, but they usually suffer from high insertion loss and poor selectivity, due to filters components' loss and low Q-factor. Thus, microwave active filters have been proposed to compensate these losses and improve the filter selectivity. There are 4 common active filter topologies well established, based namely in: negative resistance elements; active inductors; transversal, and recursive filters [1-4].

One of the active bandpass filtering structures providing high-selectivity with stability without relying on high Q-factor elements is the microwave lumped and transversal bandpass filter [3]. However, due to the intrinsic nonlinearity of the active element, the filter exhibits undesirable distortion [5]. Usually, *P1dB* and *IP3* (3rd order intercept point) are employed to characterize the dynamic range of such active filters, and recently several studies on nonlinearity were presented [6]-[7], but *P1dB* improvement study is still rare. Against this background, it is the objective of this paper to explore the *P1dB* of the microwave lumped and transversal bandpass filter devoting a special emphasis on the definition of a special technique applied to its elevation. To achieve the above *P1dB* improvement, common-drain based active feedback will be used in the transversal element to improve the overall filter's gain compression owing to its control of the input impedance variation [8]-[10], which will impose the filter's distortion characteristics linearization.

The structure of the proposed lumped and transversal filter with active feedback will be introduced in section II together with the proposed linearization method for transversal elements. In order to demonstrate the effectiveness of the proposed method, a prototype microwave lumped and transversal bandpass filter centered at 2 GHz with 15% fractional bandwidth, using constant-*k* filtering and GaAs FETs, is designed and implemented with the corresponding measurement results presented and discussed in section III. Finally, the conclusions will be drawn in section IV.

II. MICROWAVE LUMPED AND TRANSVERSAL FILTER WITH ACTIVE FEEDBACK TRANSVERSAL ELEMENTS

The microwave lumped and transversal bandpass filter shows resemblance with the digital transversal filter, but applied to the operation in microwave frequencies. A conventional lumped and transversal bandpass filter (with *N*-sections) is depicted in Fig 1, comprising low-pass and high-pass filter sections leading to a basic bandpass filter response, with filter band-edges sharpened through signal cancellation by gain control of the transversal elements M_i (i = 1..N).

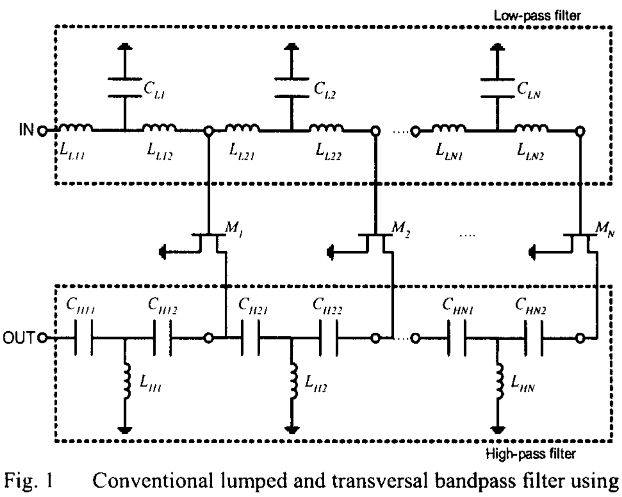

Fig. 1 Conventional lumped and transversal bandpass filter using constant-*k* filter sections (*N*-lowpass plus *N*-highpass) and *N* transversal elements in common-source configuration.

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Similar to its digital counterpart, the transfer characteristic of the lumped and transversal bandpass filter can be formulated by:

$$H(j\omega)=\sum_{i=1}^{N} A_i e^{-j\omega\tau_i} \qquad (1)$$

where ω is the angular frequency, A_i is the gain of the i^{th} transversal element and τ_i refers to the time delay.

A. Low-pass and High-pass Filter Sections

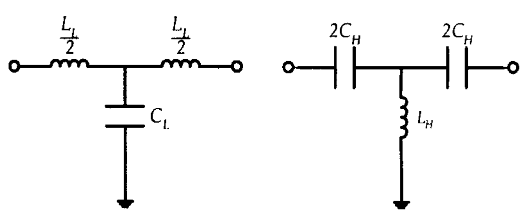
In Fig. 1, filter sections $L_{Li1}/L_{Li2}/C_{Li}$ and $C_{Hi1}/C_{Hi2}/L_{Hi}$ (i=*1..N*) are used as low-pass and high-pass filters for the microwave lumped and transversal bandpass filter respectively, and, they are designed based on constant-*k* filter sections.

The design of the constant-*k* filter sections is based on the image impedance method where the input image impedance is made equal to the output image impedance of the filter section. And, the image impedance of the constant-*k* filter section can be defined as

$$Z_{iT}=R_o\sqrt{1-\frac{\omega^2}{\omega_c^2}} \qquad (2)$$

where R_o is the nominal characteristic impedance and ω_c is the cut-off frequency in radians.

To design the low-pass constant-*k* filter section, two inductors in series with identical values together with a shunt capacitor are used, whilst the high-pass constant-*k* section consists of two equal capacitors in series and a shunt inductor, shown in Fig. 2(a) and Fig. 2(b), respectively [11].



(a) (b)

Fig. 2 (a) Low-pass and (b) high-pass constant-*k* filter sections.

The nominal characteristic impedance R_o and cut-off frequency in radians are defined as

$$R_o=k=\sqrt{\frac{L_L}{C_L}}=\sqrt{\frac{L_H}{C_H}} \qquad (3)$$

and

$$\omega_c=\frac{2}{\sqrt{L_L C_C}}=\frac{1}{2\sqrt{L_H C_H}} \qquad (4)$$

Then the element values for the low-pass and high-pass filter sections can be determined by (5) and (6).

$$L_L=\frac{2R_o}{\omega_H}; \qquad C_L=\frac{2}{R_o\omega_H} \qquad (5)$$

$$L_H=\frac{R_o}{2\omega_L}; \qquad C_H=\frac{1}{2R_o\omega_L} \qquad (6)$$

where ω_H and ω_L are the low-pass and high-pass cut-off frequencies, in radians, respectively.

B. Transversal Elements with P1dB Improvement

In the design of the microwave lumped and transversal filter, the transversal elements $M_1..M_N$ in Fig. 1 are built with common-source FET amplifier configuration. Where the active filter dynamic range is limited due to the inherent nonlinearity of the transistors M_i (i=*1..N*). In order to improve the filter nonlinearity an active feedback linearization method is utilized to elevate the *P1dB* of the transversal elements.

Fig. 3 shows the circuit schematic of a common-drain FET feedback transistor connected between the output and input terminals of the common-source transversal element. The coupling capacitors C_{f1} and C_{f2} are used to couple the common-drain FET signal with the common-source amplification FET. This circuit is thus used to replace the traditional transversal element M_i (i=*1..N*) from Fig. 1.

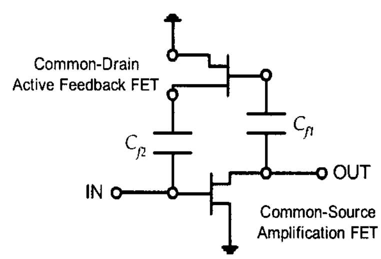


Fig. 3 Transversal element with common-drain active feedback.

The above common-drain FET offers a feedback path for the common-source FET and its transconductance controls not only the feedback transmission but also the input impedance of the common-source FET, as a consequence, the overall power gain variation can also be controlled and thus this may benefit the overall filter gain compression improvement. To evaluate this linearization method employed in the microwave lumped and transversal bandpass filter the *P1dB* of the lumped and transversal filter's transversal element using NE76038 GaAs MESFET is simulated [12] with and without active feedback. With similar linear characteristics, Fig. 4 shows a comparison between the corresponding simulated *P1dB*. Obviously, at 2 GHz, *P1dB* is obtained at -5.5 dBm input power for the transversal element without active feedback, whereas an improvement close to 6 dB is obtained when the active feedback FET is used. It is thus envisaged that the usage of this new transversal element in the microwave lumped and transversal bandpass filter contributes to the overall gain compression improvement. In addition, it is also observed that the most important contribution for the filter's power gain is derived from the transversal element M_N in the main signal path. Thus, only the main transversal element M_N with active feedback has been considered in this work.

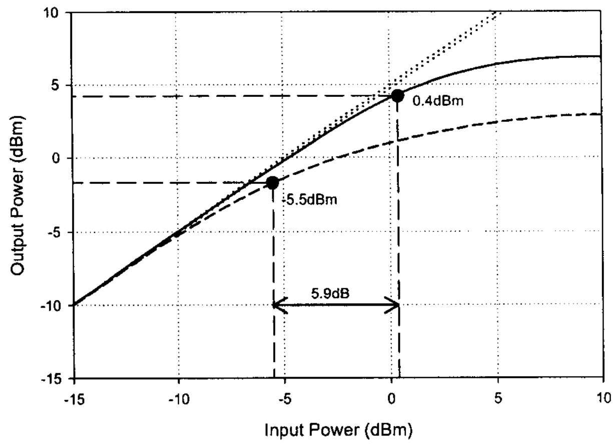


Fig. 4 Simulated $P1dB$ for the transversal element without (---) and with (—) active feedback.

III. DESIGN EXAMPLES

In order to demonstrate the usefulness of the proposed active feedback linearization method, two L-band microwave lumped and transversal bandpass filters @ 2 GHz with 15% FBW are designed with and without active feedback used in the main transversal element. As shown in Fig. 5, three cascaded constant-k low-pass/high-pass sections in microstrip implementation are used to obtain the basic bandpass filter response, and the substrate of the microstrip is RO4003 with $\varepsilon_r = 3.38$ and 1.524 mm thickness. Two transversal elements M_1 and M_2 are built using NE76038 GaAs MESFET (as mentioned in section II). The filter's $P1dB$ is dominated by the main transversal element M_2 is biased in order to achieve a relative high gain when compared with that of the auxiliary transversal element M_1. Therefore, the linearization of the transversal element M_2 can benefit the overall filter's $P1dB$ elevation. An active feedback FET transistor in common-drain configuration is added to the main transversal element M_2 for $P1dB$ improvement. These two filters are biased to obtain similar transfer characteristics and the nominal noise figure level of 4.4 dB in the conventional structure.

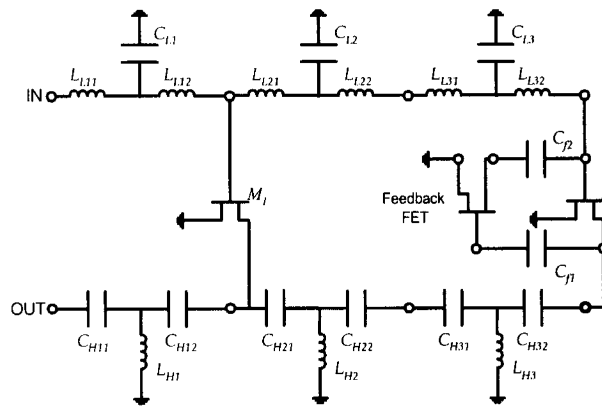


Fig. 5 Circuit schematic of the prototype microwave lumped and transversal bandpass filter with active feedback transversal element.

Fig. 6 allows the comparison of the measured $|S_{21}|$ frequency responses of the above 2 filters and; due to the transversal filtering effect, two transmission zeros are clearly observed at ~1.5 GHz and ~2.3 GHz, respectively, that indeed sharpen the filter band-edges accordingly. The passband insertion loss of these two filters is also measured in the level of 0.7 dB. By using the active feedback transistor, the transmission zero in lower side band is tuned from -30 dB @ 1.5 GHz to -40 dB @ 1.6 GHz whilst the transmission zero @ 2.3 GHz is maintained. Thus, slight passband-to-stopband transition improvement can be realized. The unwanted "kick-back" effect is mainly due to the parasitic of the active element and can be eliminated by a higher order design. In addition, the measured return loss of the filter using active feedback is also as good as 23 dB, as shown in Fig. 7.

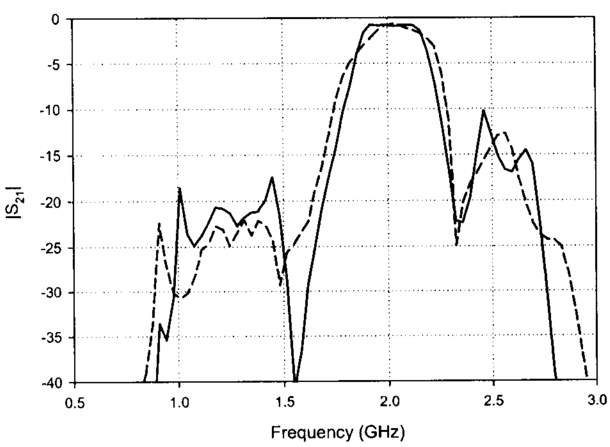


Fig. 6 Measured $|S_{21}|$ of the lumped and transversal bandpass filter without (---) and with (—) active feedback.

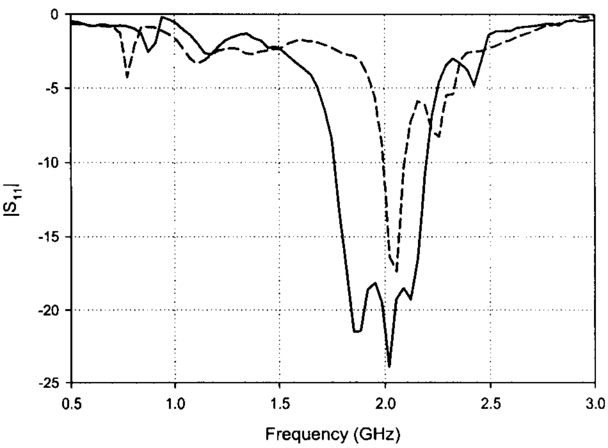


Fig. 7 Measured $|S_{11}|$ of the lumped and transversal bandpass filter without (---) and with (—) active feedback.

Besides similar transfer characteristics, as illustrated by the measured results of Fig. 6 and Fig. 7, the *P1dB* performance for the above two filters was also measured and recorded in Fig. 8. One can see that *P1dB* for the conventional lumped and transversal bandpass filter is obtained at input power of -3.5 dBm and -9.5 dBm output power. On the other hand, when the proposed active feedback is used in the main transversal element, the filter's *P1dB* is thus elevated to 3dBm and 2.4dBm of input and output powers, respectively, resulting in around 6.5dB of *P1dB* improvement. This indeed confirms the usefulness of the active feedback in the filter's gain compression elevation. Moreover, it is also noticed that additional active feedbacks used in other auxiliary transversal elements will not yield significant gain compression improvement.

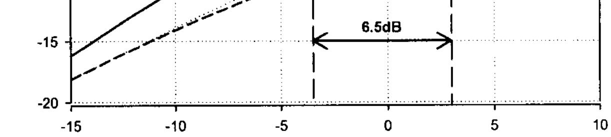


Fig. 8 Measured *P1dB* of the lumped and transversal bandpass filter without (---) and with (—) active feedback.

IV. CONCLUSIONS

A new technique to elevate the conventional microwave lumped and transversal bandpass filter gain compression using active feedback was presented. A simple approach in adding the active feedback to the main transversal element alone has been studied and demonstrated. Experimental results, based on a prototype bandpass filter @ 2 GHz with 15% FBW, confirm that a 6.5 dB *P1dB* improvement is obtained without degrading noise figure performance. The technique addressed herein can be easily extended to the design of higher order lumped and transversal bandpass filters. Moreover, this active feedback architecture can facilitate later MMIC implementations when compared with other conventional system level linearization methods.

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