A tuneable GaAs MMIC band stop filter at X-band with a novel active inductor

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Abstract

The design and performance of two tuneable GaAs MMIC band stop filters is presented.
The first filter was designed to demonstrate the excellent properties of the resonating tank consisting of a varactor diode and a novel active inductor.
On the basis of the first filter, a second filter is designed with improved performance, with respect to gain, noise figure and bandwidth. This filter is tuneable from 9 to 11 GHz, with a notch depth of more than 25 dB. The filter exhibits a gain of 4 dB which is flat within 0.5 dB from 6 to 18 GHz. The -10dB notch bandwidth amounts to 60 MHz for a 10 GHz centre frequency. Large-signal behaviour was investigated and hence we believe to report the first fully characterised MMIC tuneable narrow band stop filter at X-band.

Introduction

Receivers that are used in Electronic Support Measures (ESM) systems, are often of a wideband nature. The receivers are often used in a very agressive environment from the point of electromagnetic interference (EMI), due to the presence of different kinds of strong radar and RF signals. The ESM receiver searches the entire spectrum for hostile signals and needs blocking of the frequencies generated locally. For this problem, YIG band stop filters are conventionally used.

Due to emerging fast frequency-hopping radars, these YIG filters can no longer be used. Apart from being large, they cannot be tuned very fast and are thus not able to follow the local, fast frequency-hopping, signal.

Integrated narrow band filters are not available yet at microwave frequencies. If we would be able to integrate narrow band filters, we could benefit from the fast response times of this type of circuits. The use of MMIC technology further allows integration with other front end components and may hence result in a significant reduction of cost, size and weight of the ESM receiver.

The goal of this work is to study the feasibility of MMIC technology for EMI rejection filters, to be used in ESM receivers. Their application is, of course, not at all limited to this application. Other applications that come to mind are satellite communication systems and instrumentation equipment.

Band stop filter aspects

Only during the last few years the attention of MMIC designers has turned toward MMIC filters. The first full non-linear and noise characterisation of an MMIC band pass filter appeared last December [1], and MMIC band stop filters have gained very sparse attention. We believe to be the first to present a fully characterised MMIC narrow band stop filter at X-band.

In order to design microwave narrow band stop filters, inductors and capacitors with high quality factors Q are required. The Q of fixed, integrated capacitors is usually not problematic. Conventional MMIC spiral inductors on GaAs substrates, however, have quality factors Q (=Im[Z]/Re[Z]) of 20 at best. The situation on Silicon substrates is even worse. The losses in the inductors are mainly caused by dielectric losses in the substrate and the resistivity of the metallisation.

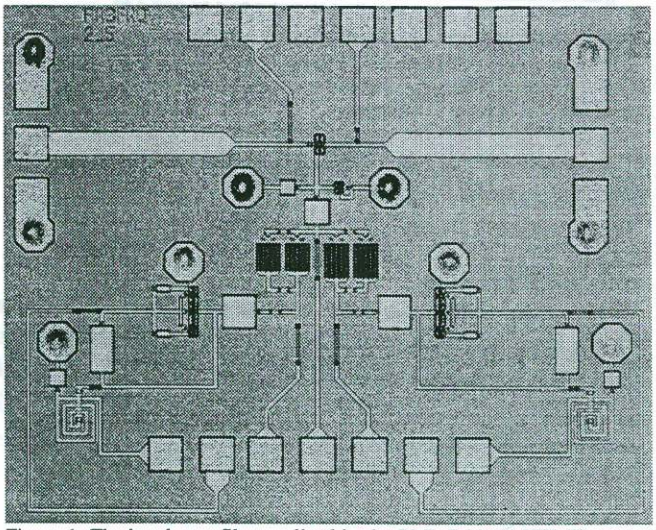


Figure 1: The band stop filter realised in the PML D02AH HEMT process (2x2 mm^2).

If a tuneable filter is required, an inductor parallel to a varactor diode can be used as the resonating tank. Unlike fixed capacitors, varactor diodes have capacitances with a low Q. By using an active inductor, we have the possibility to create a negative resistance, and the losses of the resonator circuit can be compensated giving a resonant circuit with a high Q-factor.

Active inductors are constructed of passive and active components (MESFETs and HEMTs in our case). The compensation of the losses in the resonant circuit will give the opportunity to design filters with insertion gain. Unfortunately also the drawbacks of active circuits, such as noise and large-signal behaviour, are present. In the case of band pass filters, the noise figure is often prohibitive for use in real systems. This is not the case for band stop filters, as we will see later on.

As stated, another important aspect is the limited power handling capability of the active device. High power applied to an active inductor may influence the filter centre frequency and bandwidth. Combining noise figure and maximum applied signal, it is concluded that attention must be paid to the active filter dynamic range.

Circuit design

The filters are series feedback amplifiers consisting of an FET with a resonant circuit in the source. Figure 2 shows the simplified circuit. The resonant circuit constitutes of a varactor diode and an active inductor consisting of an FET and several passive components like inductors, capacitors and resistors.

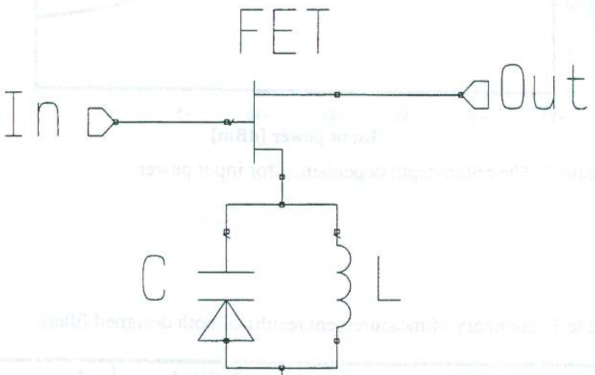


Figure 2: The simplified circuit of the band stop filters

Earlier reported examples of broad band active inductors [2,3] cover a wide range of inductance values (0.5 - 50 nH) with Q-factors ranging from poor to outstanding (5-200). These active inductors perform up to roughly 30% of the transition frequency of the employed device (0.3 f_T). Increasing the high-frequency properties of active inductors requires a different approach. Instead of realising a broadband active inductor, we have focussed on narrow band active inductors [4,5]. A simplified schematic of the active inductor is shown in Figure 3.

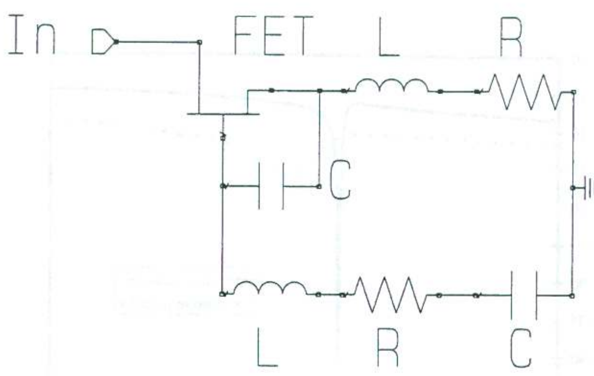


Figure 3: Simplified schematic of novel active inductor.

Two narrow band stop filters are designed as MMIC on GaAs. The first filter was designed to demonstrate the excellent properties of the resonating tank which includes the novel active inductor. No effort is put into the optimisation of the input and output return losses and the conversion gain/loss of the filter. The filter is designed in the standard D05ML GaAs process of Philips Microwave Limeil (PML). This process includes 0.5 µm MESFETs with an f_T of 24 GHz.

The second filter is designed with the specifications of the ESM receiver in mind. Insertion gain as well as noise figure and notch depth and bandwidth were the main design specifications. By applying two resonator circuits in the source of the amplifier, the tuning bandwidth is expanded to almost twice the tuning bandwidth of a single resonator. This was necessary due to the lack of optimised varactor diodes. Now that these have become available, it is anticipated that the tuning range could be enlarged. Selection of the resonator circuit is done by switching a bias voltage. It is also possible to use two notch frequencies simultaneously.

The active inductor allows filter designs up to more than ½ f_T. For this filter the standard PML D02AH process is chosen. The process includes 0.2µm HEMTs with an f_T of 53 GHz. Using this process not only allows filter designs for higher frequencies but also gives better stopband performance due to lower active device parasitics. Figure 1 depicts the realised band stop filter in the PML D02AH process.

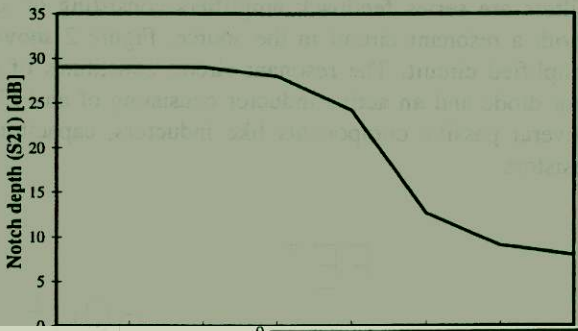
Measured results

Several aspects of the notch filters have been characterised unpackaged between 2 and 20 GHz with a measurement setup employing an HP8510C, HP8970B, HP8971C and a temperature-controlled chuck.

Figure 4 shows the small signal measurement results of the initial design. The notch, tuneable from 9 to 11 GHz, is compared with the measured notch resulting from an identical filter where the active inductor was replaced with an active inductor.

The measured notch under large-signal conditions is shown in Figure 7. No change in the notch frequency due to large input signals was observed.

The filter has also been characterised as a function of temperature between 20 and 60 °C. Effects on the notch frequency were again not observed and the effect on the notch



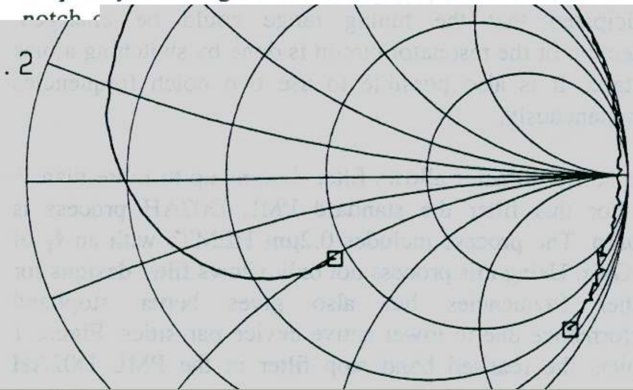
The notch depth dependency for input power

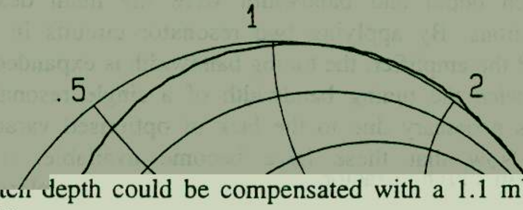
Summary of measurement results of both designed filters.

cification	Initial	Improved
ing range	9-11 GHz	9-11 GHz
ch depth	30 dB	30dB

Figure 6: Small signal and noise figure of the second filter design.

Figure 5 shows the measured impedance of the ac inductor. Figure 6 depicts the small signal measureme now for the second design, together with the noise fig Please note that this noise figure has been achieved wit any noise matching.





notch depth could be compensated with a 1.1 mV/°C shift.

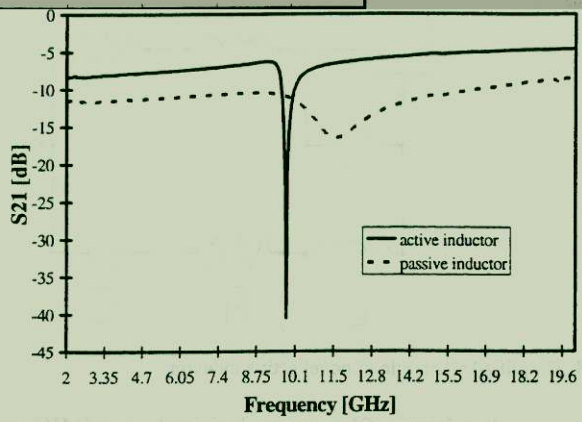
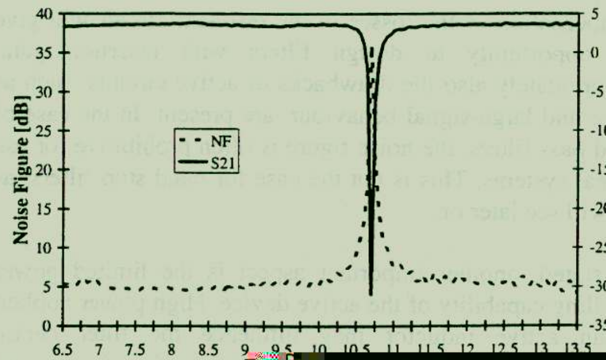


Figure 4: The initial filter design with active inductor and passive inductor.



Conclusion

A tuneable MMIC band stop filter at X-band realised on GaAs is demonstrated. The filter uses a novel active inductor.

In summary, the specifications amount to a 30 dB notch depth which can be tuned between 9 and 11 GHz, a gain of 4 dB, flat from 6 to 18 GHz, a notch bandwidth of 60 MHz, and a noise figure around 5 dB. The filter has been fully characterised in terms of small- and large-signal behaviour and noise figure.

The filter shows promising results for application in future Electronic Support Measures (ESM) receivers but can also be used for other applications. Due to the small size, integration with other receiver components is feasible.

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