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Low-Noise Band Selective Amplifier and Active Equalizer with Controlled Gain-Slope for 3.4 – 4.6 GHz

V. Vassilev[1], I. Angelov[2], S. Kovtonyuk[1] and V. Belitsky[1]

[1] *Onsala Space Observatory, Chalmers University of Technology*

[2] *Department of Microwave Technology, Chalmers University of Technology*

Abstract

We present the design and the performance of a low-noise band-selective amplifier and low-noise tuneable active equalizer for frequency band 3.4-4.6 GHz.
The band-selective amplifier has a precisely defined pass-band gain-curve that reduces the out-of-band noise coming from the preceding amplifier, and helps avoiding possible spectra distortion due to the high overall gain (>70 dB) . The amplifier provides gain of 40dB within the pass band (3.3-4.7GHz) and 6dB roll-off at 3 and 5.2 GHz with noise temperature of 190° K.
The equalizer was designed to compensate the frequency dependent losses of a 50m coaxial cable that connects the receiver in the antenna cabin to the spectrum analyser (correlator) in the control room. The equalizer achieves 11 dB gain at 4.6GHz with a typical noise temperature of 190° K and provides a linear slope of 3.5 dB at 3.4GHz. The possibility to tune the AEQ gain-slope is provided by PIN diodes as voltage controlled resistors. The slope can be varied by ±0.7 dB without disturbing the slope-linearity.

1. Introduction

MM waves super heterodyne receivers used in radio astronomy have relatively high intermediate frequency (IF), which for Onsala Space Observatory is adopted to be 3.4-4.6GHz. A low-noise IF band selective amplifier was designed and tested as a stage of the IF chain for Onsala 3-mm band receiver. This room temperature amplifier follows the cooled low-noise IF amplifier (4K ambient temperature). Because of the very high overall gain of the IF chain (70 dB), out of the band noise causes gain-compression (saturation) and non-linear spectrum distortions. We have designed a low noise amplifier for 3.4-4.6 GHz band with gain of about 40 dB, gain flatness ± 0.3dB and noise temperature <200K over the band. The amplifier's precisely defined gain-curve forms an active band-pass filter suppressing the unwanted out-of-band noise. The signal is further coupled to the spectrum analyser (correlator) placed in the control room 50 m from the antenna via coaxial cable. The cable-loss has linear frequency dependant slope that depends on the physical characteristics of the cable and its length. This slope can be compensated by connecting the cable output to an equalizer having a gain-slope opposite to that of the cable. A low-noise tuneable active equalizer (AEQ) was designed to compensate for 3.5 dB slope within 3.4 - 4.6 GHz IF band [1]. The AEQ gain-slope control gives the opportunity to tune the equalizer's slope and thus to adjust the flatness inside the IF band. Both the band selective amplifier and the AEQ are designed using 1.5-8 GHz low noise MMIC [2] as an active element.

2. Low-Noise Band Selective Amplifier Design

To meet the requirements described above we choose to use two MMIC gain blocks coupled through a band-pass filter structure (coupled lines) to provide the required band-pass gain-shape. Similar filter structure is used at the output providing both matching for the gain block and additional band-pass filtering. The amplifier input circuitry consists of two sections matching circuit, that provides low input reflection in order not to affect the performance of the preceding cryogenic amplifier optimised for the lowest noise. Figure 1 shows the amplifier block-diagram. Figure 2 displays a picture of the device.

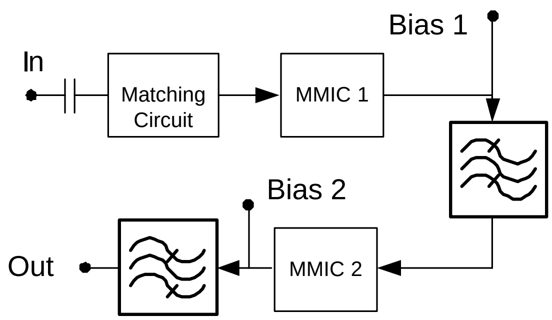

Figure 1 Band-selective amplifier block diagram.

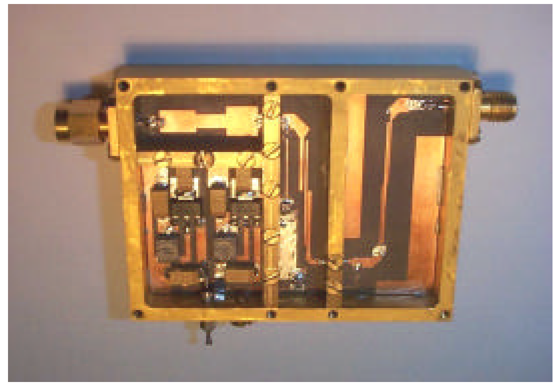

Figure 2 Photograph of the band-selective amplifier.

We can slightly vary the MMIC S parameters by changing their respective supply voltages. To do this we use two tuneable inbuilt voltage supply stabilizers to bias the gain blocks. Thus, by varying the supply voltages we can adjust the required gain and also to some extent fine-tune the gain-flatness and its frequency dependence via modifying the MMIC S-parameters. The simulated [3] and the measured gain are plotted in Figure 3. Figure 4 displays the measured input and output reflections.

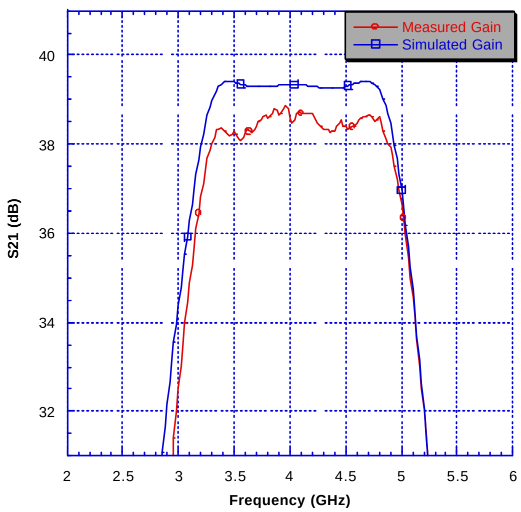

Figure 3 Measured and simulated gain.

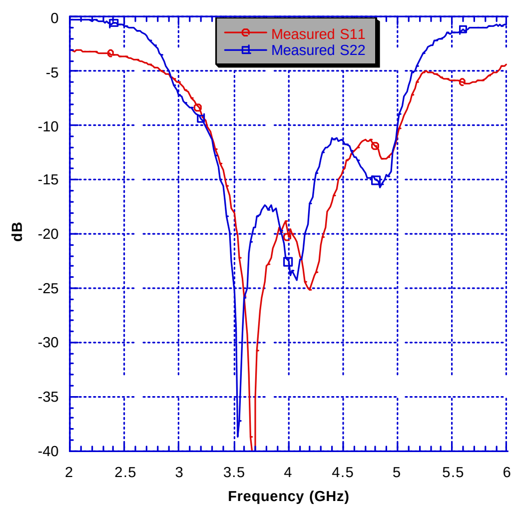

Figure 4 Measured input and output reflection.

The preceding cryogenic amplifier is optimised for minimum noise in the pass-band, but has broader gain bandwidth than the specified IF band and this result in substantial out of band noise (e.g. around 5GHz). To avoid possible standing waves at the input the matching circuit was optimised for minimum reflection in wider 3-5.2 GHz band. Though the input matching was design for minimum reflection, the measured noise is very close to the optimum. The noise temperature/noise figure of the device was measured and the result is plotted in Figure 5, the same plot shows the producer-specified MMIC noise performance.

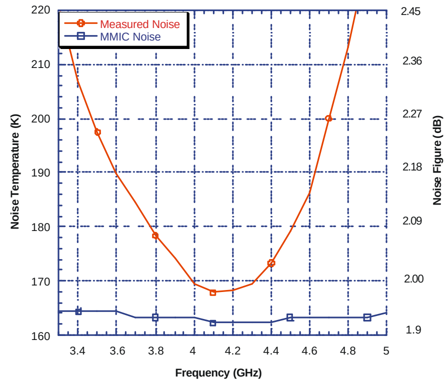

Figure 5 Amplifier's measured noise and the producer specified gain block noise.

3. Design of an Active Equalizer with Controlled Gain-Slope.

It is possible to create a linear slope over the gain of an active element by coupling the output of the active element to a resonant circuit tuned to frequency above the highest frequency in the pass band *Fu*. Doing this, loss less impedance matching is provided for *Fu* and increasing attenuation is introduced with decreasing the frequency. A suitable structure is the one containing a short-circuited $l_u/4$ shunt stub with a connecting line as shown in Figure 6.

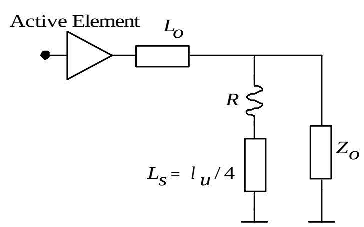

Figure 6. Introducing a slope over the gain of an active element.

Since the gain-slope is provided as a result of reactive mismatch, it causes increased standing waves at the output circuitry of the equalizer. Introducing resistance in series with *Ls*, as shown in Figure 6, creates resistive losses for the frequencies at the low- and mid-band and thus improves the VSWR. Moreover, change in the resistance value allows regulating the filter Q-factor and thus adjusting the slope.

The block-diagram of the AEQ is shown in Figure 7. In order to provide slope adjustment, the overall slope-generation circuitry is divided between two symmetrical and identical branches. The first branch gives the initial and fixed slope of 3.5 dB over 3.4-4.6 GHz, while the second slope-generating branch allows fine slope adjustment. For this purpose we use PIN diodes [4] as a voltage-controlled resistance. The diode's parasitic leads inductance along with the parasitic capacitance of *0.3 pF* confine the values of obtainable PIN diode intrinsic resistance within the range of *22 <R<115* at frequency of 4.6 GHz. As a result of these limitations, the AEQ can provide linear slope from 2.8 dB up to 4.2 dB within the band 3.3-4.6 GHz (Figure 9).

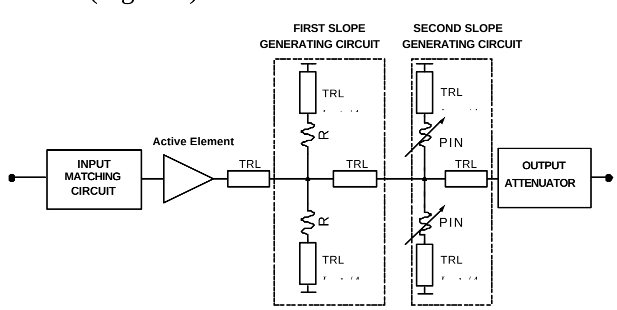

Figure 7 The AEQ block diagram.

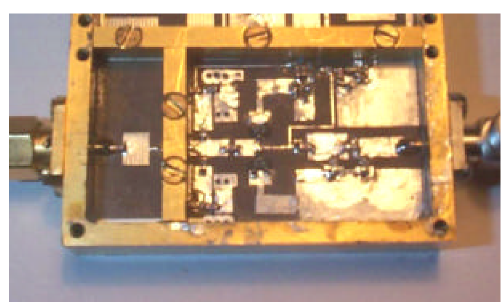

Figure 8 Photograph of the AEQ.

The gain-slope generation via reactive mismatch causes poor VSWR at the output circuitry for the mid- and low frequencies in the band. It is difficult to achieve output matching better than *S22=-3 dB* at the lower band edge. In order to improve *S22* we use an attenuator type matching circuit. That allows *S22* being below *10 dB* over the working band. The measured gain of the equalizer versus frequency is plotted in Figure 9 for four values of the PIN diode resistance, which determines the region, where the slope remains linear within the pass-band 3.4-4.6 GHz. The measured input and output reflection is plotted in Figure 10.

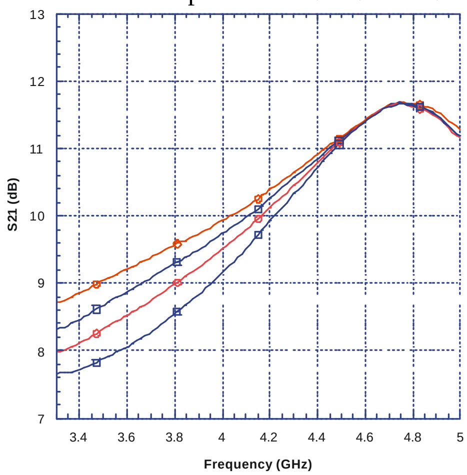

Figure 9 Measured gain of the AEQ for four values of the PIN diode resistance.

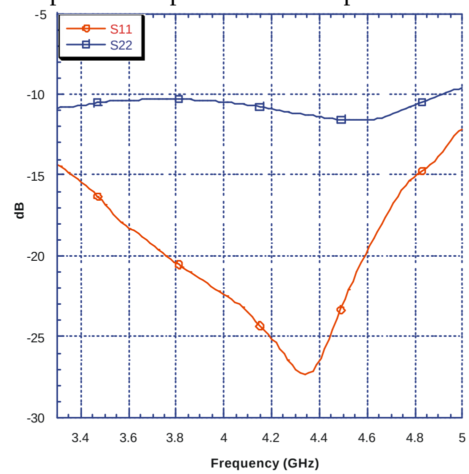

Figure 10. Measured input (solid line) and output (dashed line) reflection coefficient.

The equalizer was mounted and tested at Onsala Space Observatory and Figures 11, 12 show the measured cable slope before and after the equalization.

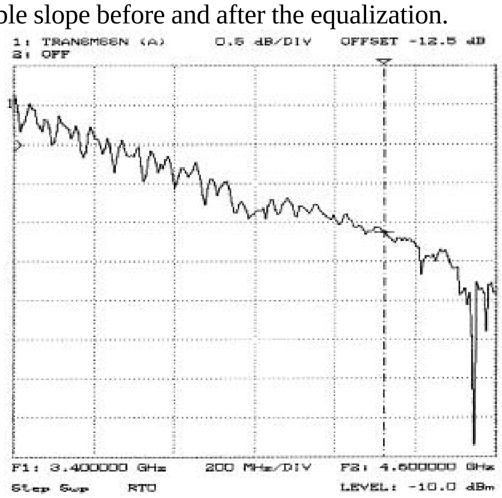

Figure 11 The cable slope before the equalization.

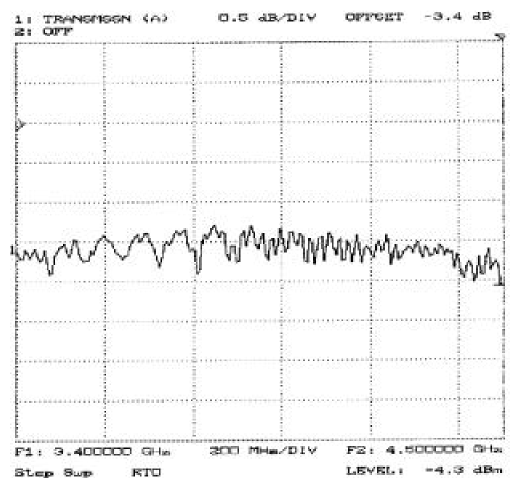

Figure 12 The compensated cable slope.

Conclusion

A band selective amplifier (active pass-band filter) and active equalizer are designed and measured as a stage of the 3 mm band Radio Camera Project for Onsala Space Observatory (OSO). The devices were tested in real working conditions. The measured performance is in a good agreement with the simulations.

References

1. Vessen Vassilev, Ilcho Angelov and Victor Belitsky, ”Design and Performance of a 3.4 to 4.6 GHz Active Equalizer with Controlled Gain Slope” Applied Microwave&Wireless December 1999.
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