Design and Performance of a 3.4 to 4.6 GHz Active Equalizer with Controlled Gain-Slope

This circuit is designed to provide adjustable compensation for cable losses

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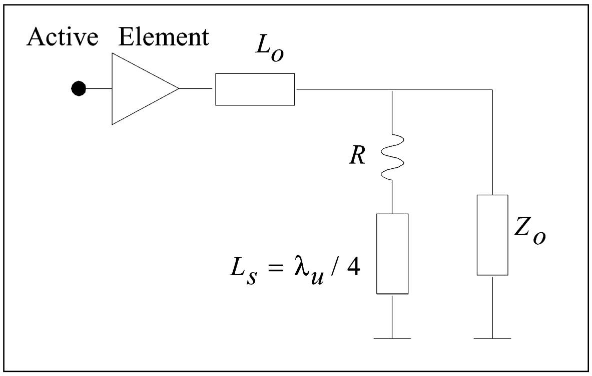
This article presents the design and performance of a low-noise tuneable active equalizer (AEQ) intended to compensate for frequency dependent losses in the coaxial cable. The equalizer achieves 11 dB gain with a typical noise figure of 2.2 dB and has a slope of 3.5 dB within the 3.4 to 4.6 GHz band. Two PIN diodes serving as voltage-controlled resistors provide the ability to tune the AEQ gain-slope and hence obtain accurate flatness inside the passband. The slope can be varied by ±0.7 dB without disturbing slope linearity.

Using coaxial cable as a transmission medium introduces the problem of compensating the slope inside the desired frequency band due to the cable's frequency dependent attenuation. The cable slope is linear and depends on the physical characteristics of the cable and its length. This slope can be compensated by connecting the cable's output to the equalizer having a slope opposite to that of the cable. Additional signal slope can also appear as a result of inconstant power gain of amplifiers matched for minimum noise figure. A technique used to compensate for the MESFET's gain-slope and thus to achieve a flat amplification has been presented in [1] and [2]. A passive microwave fixed-slope equalizer is reported in [3], where a direct-coupled bandpass filter topology has been used.

The equalizer desribed here was designed to compensate for 3.5 dB slope within the 3.4 to 4.6 GHz IF band used in radio astronomical spectral line observations. The front-end receiver placed next to the focal plane of the antenna is connected via coaxial cable to the correlator-spectrometer located in the control room. The AEQ gain slope control gives the opportunity to tune the equalizer's frequency response slope and thus to adjust the flatness inside the IF band. This article suggests a possible structure for an AEQ with linear and adjustable gain-slope.



▲ **Figure 1. To create a slope over frequency, an active element resonates with the output reactance at frequency above the pass band. The shunt branch contains short-circuited stub tuned to the same frequency.**

Equalizer design

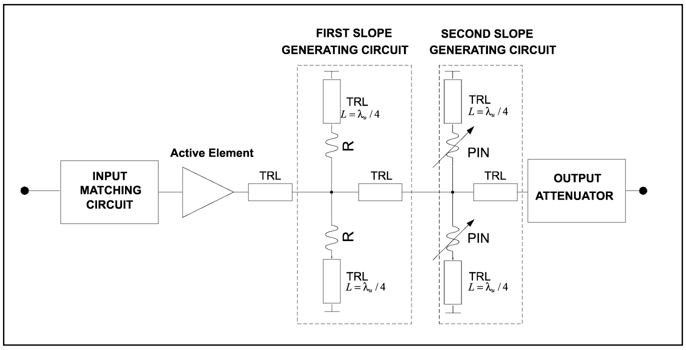
It is possible to create a linear slope over the gain of an active element (HP MGA-86576) by coupling the output of the active element to a resonant circuit tuned above the highest frequency in the pass band f_u. Using this method, lossless impedance matching is provided for f_u and increasing attenuation is introduced as the frequency decreases. A suitable structure contains a long short-circuited shunt stub ($\lambda_u/4$) with a connecting line (Figure 1).

The high impedance series transmission line L_0 resonates with the active element output reactance at the frequency (f_u) above the bandpass. L_s is a short-circuited shunt stub that is resonant at the same frequency. At f_u, no power is dissipated in the resistor (R) due to the high impedance in the shunt branch. Thus, maximum power is transferred to the load Z_0. Below f_u, the L_0 impedance decreases and the shunt branch introduces frequency-dependent losses.

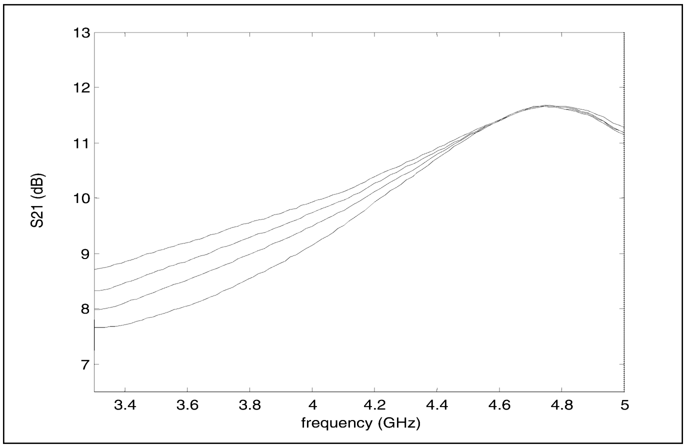
Since the gain-slope is provided as a result of reactive mismatch, it leads to increased standing waves at the output circuitry of the equalizer. Introducing resistance in series with L_s, as shown in Figure 1, creates resistive losses for the frequencies at the low- and mid-band and thus improves the VSWR. Moreover, changing the resistance value allows control of the filter Q-factor, thus adjusting the slope. The block-diagram of the AEQ is shown in Figure 2.

In order to provide slope adjustment, the overall slope-generation circuitry is divided between two symmetrical and identical branches (Figure 2). The first branch gives the initial and fixed slope of 3.5 dB over 3.4 to 4.6 GHz, while the second slope-generating branch allows fine slope adjustment. For this purpose, we use PIN diodes (HP HSMP 4810) as a voltage-controlled resistance. This diode features a total parasitic inductance of 0.75 nH, which is low compared to the parasitic inductance typical for a SOT-23 package and is designed for use at frequencies higher than the upper limit for conventional SOT-23 PIN diodes. The diode's parasitic lead inductance, along with the parasitic capacitance of 0.3 pF confines the values of obtainable PIN diode intrinsic resistance within the range of 22 ohms and 115 ohms 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 of 3.3 to 4.6 GHz (Figure 3).

A matching circuit at the AEQ input is minimally tuned at the center of the bandpass (Figure 4). As described above, the gain-slope generation via reactive mismatch causes poor VSWR at the output circuits for the mid and low frequencies in the band. It is difficult to

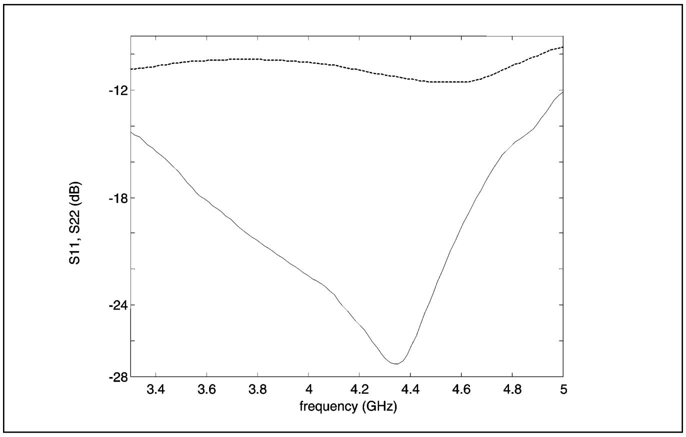


▲ **Figure 2. The AEQ block diagram.**

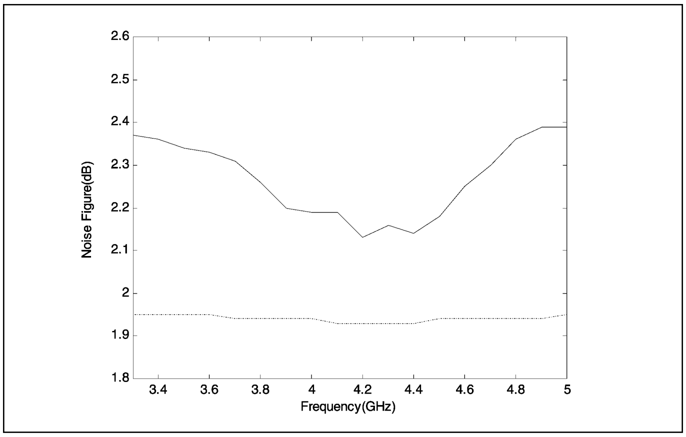


▲ **Figure 3. Measured gain of the AEQ for four values of the PIN diode resistance.**

achieve output matching better than $s_{22} \leq 3$ dB at the lower band edge. In order to improve s_{22}, we use an attenuator-type matching circuit at the output of the experimental prototype. That allows s_{22} to be better than –10 dB over the working band. Simulations and optimizations were carried out independently with two CAD software [4, 5].



▲ **Figure 4. Measured input (solid line) and output (dashed line) reflection coefficient.**



▲ **Figure 5. Measured noise figure of the equalizer (solid line) and MMIC NF when matched for maximum gain (dashed line).**

Measured performance

The measured gain of the equalizer versus frequency is plotted in Figure 3 for four values of the PIN diode resistance, which determines the region where the slope remains linear within the passband of 3.4 to 4.6 GHz.

The measured input and output return loss performance of the AEQ is plotted in Figure 4. The minimum is reached at the center of the band, whereas the minimum in s_{22} is positioned above the highest pass-band frequency 4.6 GHz.

The noise figure (NF) of the AEQ is plotted in Figure 5 together with the NF specified from the manufacturer for the gain block. Though the input matching circuit is optimized for maximum gain, the minimum in the noise performance is located at the middle of the pass-band.

Conclusion

A low-noise adjustable active equalizer has been designed and tested. The equalizer's measured gain is 11 dB with a typical noise figure of 2.2 dB. The device has a linear adjustable slope from 2.8 dB up to 4.2 dB within the 3.4 to 4.6 GHz band. The attenuator type matching circuit is used at the output of the equalizer to provide output reflection below –10 dB. The predictions from the simulations agree with the prototype measurement results. ■

References

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