A Wide-Band Low-Distortion Ferrimagnetic Attenuator

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Abstract

An electronically-controlled attenuator is presented which incorporates readily-available ferrite materials. A primary goal of the design is to attain a high level of intermodulation (IP_3) performance while at the same time keeping circuit complexity and cost at a minimum. A secondary goal is to reduce, if not eliminate, the temperature dependence normally associated with variable-gain stages. Test results show that these goals are easily achieved.

Introduction

Signal level control is an important aspect in the design of RF systems, and implementations are commonly achieved in the form of variable-transconductance amplifiers or PIN diode attenuators which, although convenient, often bear with them the undesirable characteristic of being susceptable to intermodulation distortion at relatively low signal levels, often leaving the system designer with little choice but to place these functions at low signal level points within the system.

The nature of variable gain precludes the use of negative feedback for linearization, thus compelling the circuit designer to deal directly with the non-linearities and temperature dependencies of bipolar transistors, FETs, and PIN diodes, often at the expense of using excessive biasing currents to place the devices in an operating region that offers acceptable linearity performance.

In the unique case of bipolar variable-transconductance amplifiers, the signal gain is directly related to the collector current. At higher gains, and thus higher collector currents, the devices are operating in a region of relatively high linearity and relatively small input signal levels, which is a preferable condition. At lower gains, however, the signal levels are much greater, and the decreased collector current places the devices in a region of lesser linearity, which is an undesireable condition. The consequence of using lower collector currents to obtain less gain in the presence of stronger signals is that the intermodulation performance degrades rapidly.

Recent applications of saturable-core variable inductors (transductors)[1] prompted a further investigation in the use of saturable ferrites as elements of current-controlled attenuators. It has been shown previously that ferrites exhibit good linearity properties[1], and also that transformers can be constructed in which the applied biasing magnetization is used to control the mutual coupling between two windings on a common core[2]. These earlier realizations were ungainly, and expensive, to construct which undoubtedly led to their limited application, and eventual demise.

Description

A similar device is now presented which is far simpler, and therefore less expensive to construct, and which exhibits good linearity and wide-band response. Referring to Fig. 1, a schematic representation of the device is shown. Here, the

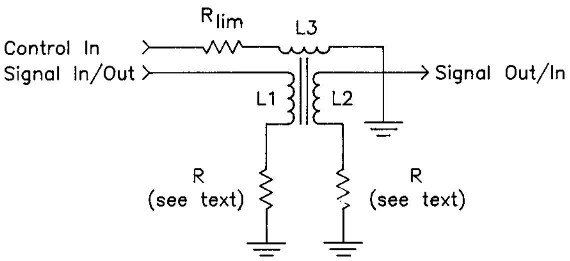

Figure 1 - Ferrimagnetic Attenuator Schematic

transformer consists of two windings, an input (L1) and an output (L2), as well as a third control winding (L3). A current-limiting resistor (R_{lim}) is placed in series with the control winding so as to set the maximum control current, and optional resistors (R) are added in series with the input and output windings to aid in impedance matching, as well as improving the controlled response. For demonstration purposes, tests were conducted with and without 51 ohm series resistors in order to demonstrate the extremes of controllability.

A mechanical description of the device is shown in Fig. 2. Here, the attenuator is constructed on a pair of E-cores, in this case Philips E13/7/4-3F3. The 3F3 material is normally considered to be useable at 1MHz and below[3] but, as will be shown later, the losses normally associated with the ferroresonance of the material[4,5] are not a factor. In the construction, a control winding is made on a suitable bobbin, in this case 600 turns of 38AWG enameled wire on a Philips E13/7/4-1S-6P coil former. The control winding is connected to the centre-most terminals of the coil former. The E-core halves are then assembled in the usual manner, using a suitable cement to fix the two core halves together. The two transformer windings are then wound on the exposed outer arms of the core, connected to the outer-most terminals of the coil former, and for demonstration purposes two such transformers were constructed, the first having 4 turns for L1 and L2, and the second having 12 turns.

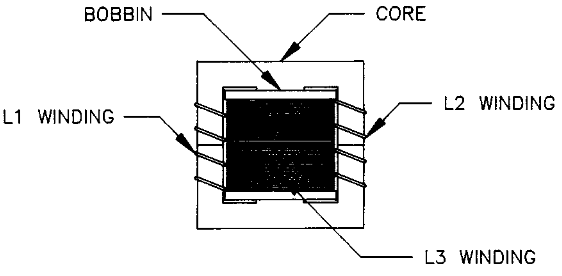

Figure 2 - Ferrimagnetic Attenuator (mechanical)

Test Results

The test results indicate that some performance trade-offs are to be taken into consideration in the design. Referring to Fig. 3, the IP_3 of the 4-turn attenuator with the 51-ohm series resistors is roughly +30dBm, whereas without the resistors the IP_3 is a very respectable +40dBm, as shown in Fig. 5. However, the presence of the resistors does determine the amount of control that can be obtained with a given applied control current, as is shown in Figs. 4 and 6. In the former, with the 51 ohm series resistors, 15dB of control can be had at 30MHz with 60mA of control current. In the latter, which is without the resistors, slightly less than 10dB of control is available at this current. Also notice that at the lower frequencies there is more insertion loss with the 51 ohm resistors present, although the response is considerably flatter at lower attenuation settings. The 4-turn attenuator is shown to be usable to at least 50MHz, and the ambient ferroresonace of the 3F3 material at 3MHz, which would normally result in increased loss, does not appear to be a factor in the performance.

Referring now to Figs. 7 through 10, similar test results are shown for the 12-turn attenuator. As might be expected from the increased number of transformer turns, this device is suitable for lower frequency applications. The +30dBm and +40dBm IP_3 performance of the previous example is also attainable here (Figs. 7 and 9, respectively), as is the reduction in controllability with the 51 ohm series resistors removed (Figs. 8 and 10).

Limited intermodulation measurements were made for various levels of attenuation, but were restricted by test equipment dynamic range and available signal power levels. Tests did show that the performance measured thus far prevails for at least the lower levels of attenuation control, and if experience should be a suitable guide it can be expected that the performance overall will remain superior to that of more conventional methods.

Extensive performance measurements over temperature have not yet been completed, however preliminary tests indicate that for the 4-turn attenuator without the 51 ohm resistors, at a -10dB attenuation setting the attenuation has a negative gradient of approximately -0.03dB/°C, which compares favourably with bipolar variable transconductance amplifiers.

Conclusions

The ferrimagnetic attenuator shown here demonstrates that such a device is a viable system component in receiver and transmitter design. By virtue of its intermodulation performance, this device is highly usable in the initial stages of a receiver, where bandwidths are at a maximum and the system is most susceptible to interference from strong adjacent signals, as well as in transmitter exciter and driver stages, where distortion products usually dictate the use of otherwise unnecessary, and costly, filtering. Further experimentations with alternative ferrite materials such as Philips 3D3 may provide a means of further improving the temperature characteristics of the device.

Acknowlegements

I would like to express my appreciation to Eastern Components, who supplied the Philips materials used in these experiments.

References

1. Trask, C., "The Forgotten Use of Saturable-Core Inductors (Transductors)," Applied Microwave & Wireless, Sep/Oct 1997, pp. 76-82.

2. Jackson, R.C. and A.W. Simpson, "A High Frequency Ferrimagnetic Attenuator," Electronic Engineering, Apr 1962, pp. 246-248.

3. -----, "Soft Ferrites," Data Handbook MA01, Philips Components, 1996.

4. Snelling, E.C., "Soft Ferrites: Properties and Applications, 2nd ed.," Butterworths, 1988.

5. Bozorth, R.M., "Ferromagnetism," IEEE Press, 1993.

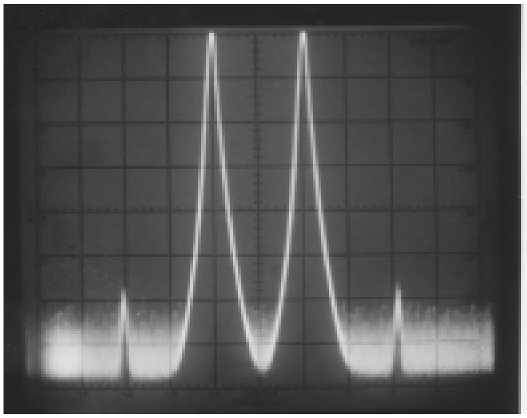

Figure 3 - 4-turn Attenuator with 51 ohm Resistors (Ref = 0dBm, 10dB/Div, F1 = 9.9MHz, F2 = 10.1mhz, ICONT = 0mA)

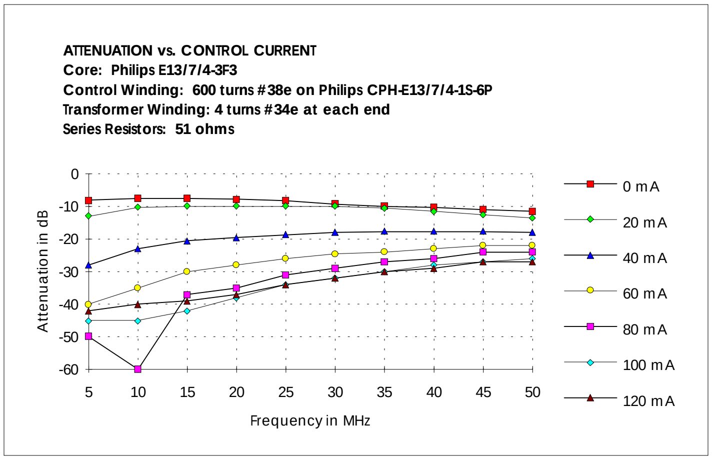

Figure 4 - Attenuation Characteristics (4-turn Attenuator with 51-ohm resistors)

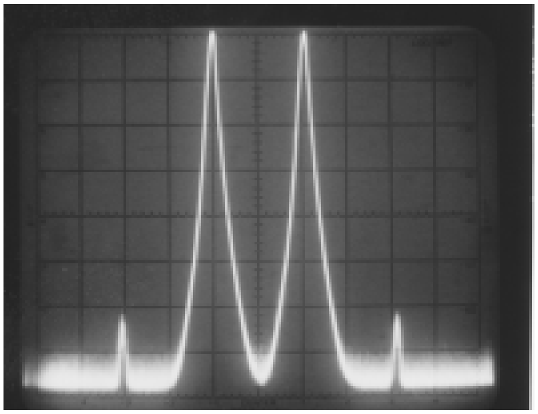

Figure 5 - 4-turn Attenuator without 51 ohm Resistors (Ref = +10dBm, 10dB/Div, F1 = 9.9 MHz, F2 = 10.1 Mhz, ICONT=0mA)

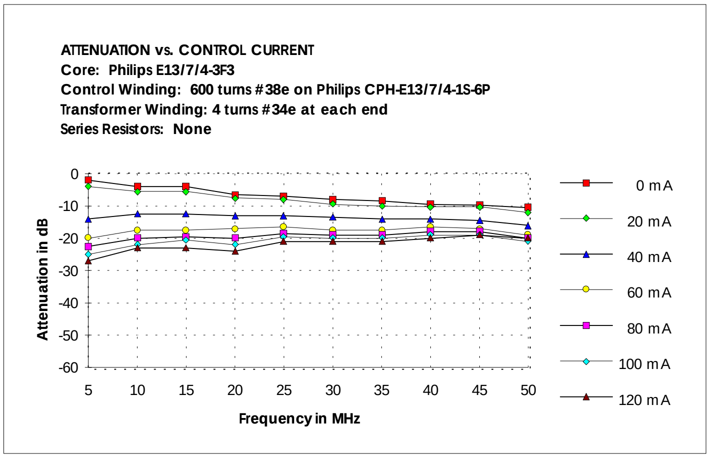

Figure 6 - Attenuation Characteristics (4-turn Attenuator without 51-ohm resistors)

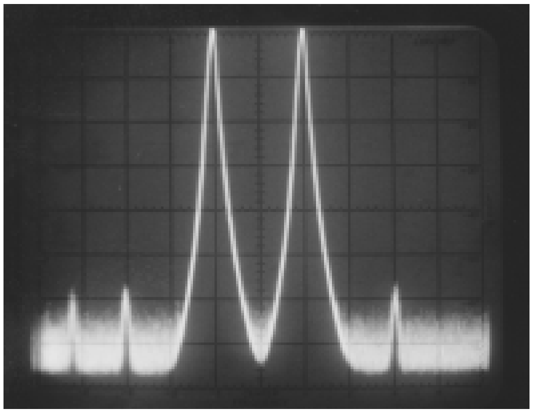

Figure 7 - 12-turn Attenuator with 51 ohm Resistors (Ref = 0dBm,10dB/Div, F1 = 1.9MHz, F2 = 2.1mhz, ICONT = 0mA)

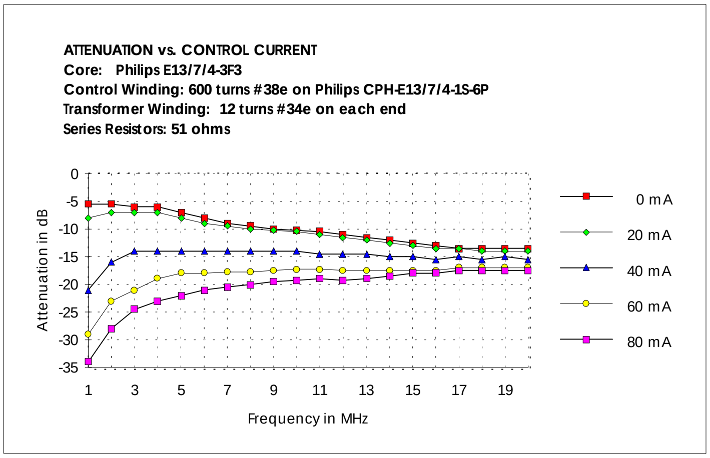

Figure 8 - Attenuation Characteristics (12-turn Attenuator with 51-ohm resistors)

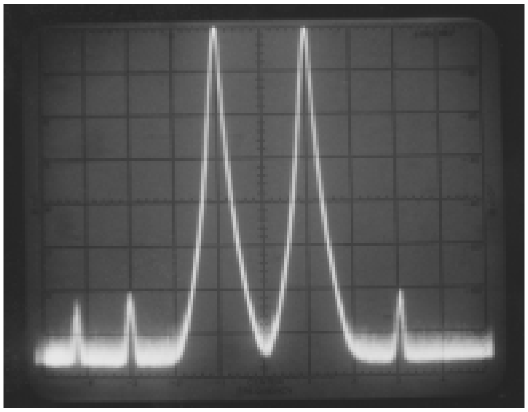

Figure 9 - 12-turn Attenuator without 51 ohm Resistors (Ref = +10dBm, 10dB/Div, F1 = 1.9 MHz, F2 = 2.1 Mhz, ICONT = 0mA)

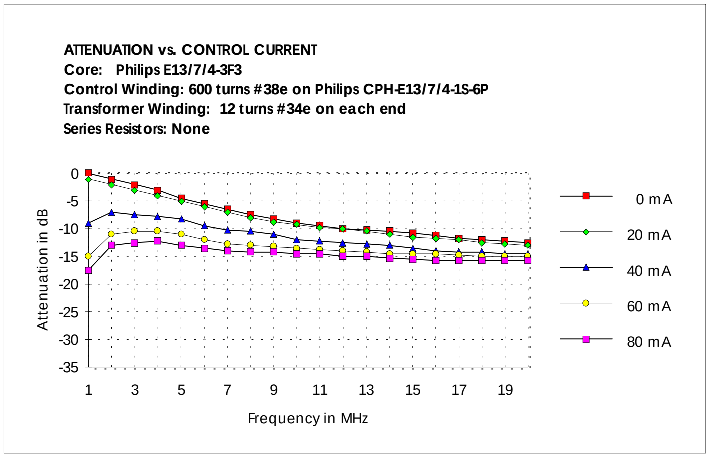

Figure 10 - Attenuation Characteristics (12-turn Attenuator without 51-ohm resistors)