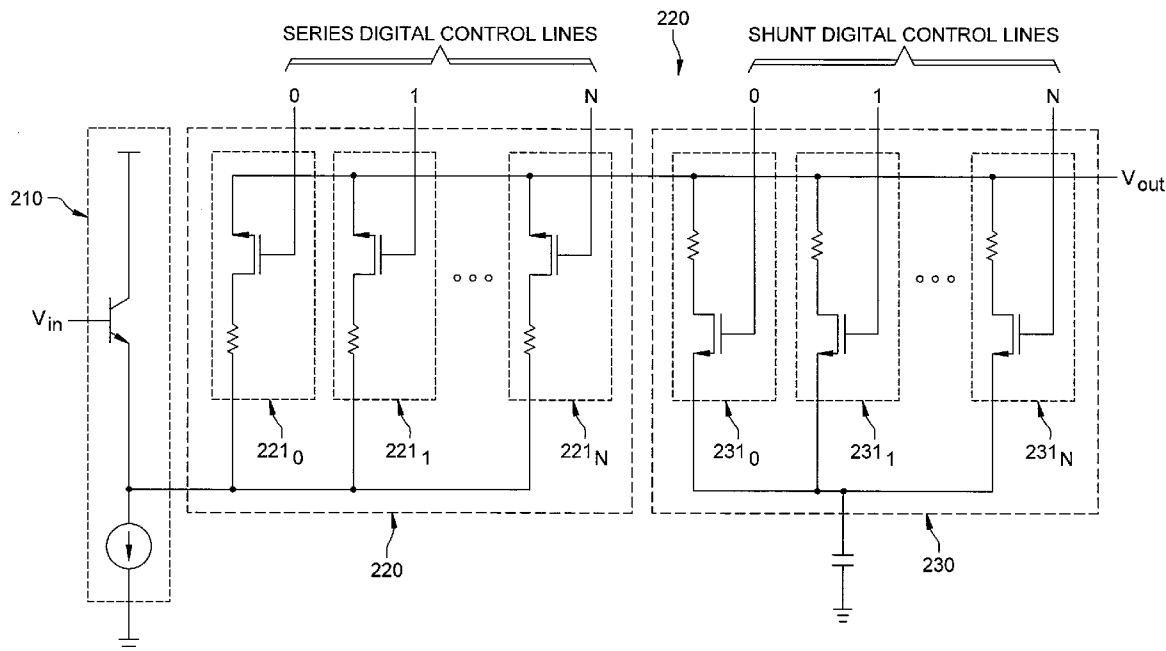




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Stevenson(10) **Pub. No.: US 2009/0167403 A1**(43) **Pub. Date: Jul. 2, 2009**(54) **AGC METHOD USING DIGITAL GAIN CONTROL**(75) Inventor: **Jan-Michael Stevenson**, Frisco, TX
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May 26, 2006, now Pat. No. 7,477,085.**Publication Classification**(51) **Int. Cl.**
H03L 5/00 (2006.01)(52) **U.S. Cl.** **327/308**(57) **ABSTRACT**

An attenuator system includes a first adjustable impedance component on a first current path between an input component and an output component, and a second adjustable impedance component between the first current path and ground, wherein each of the first and second adjustable impedance components include a plurality of selectable, discrete legs, each leg having an impedance.



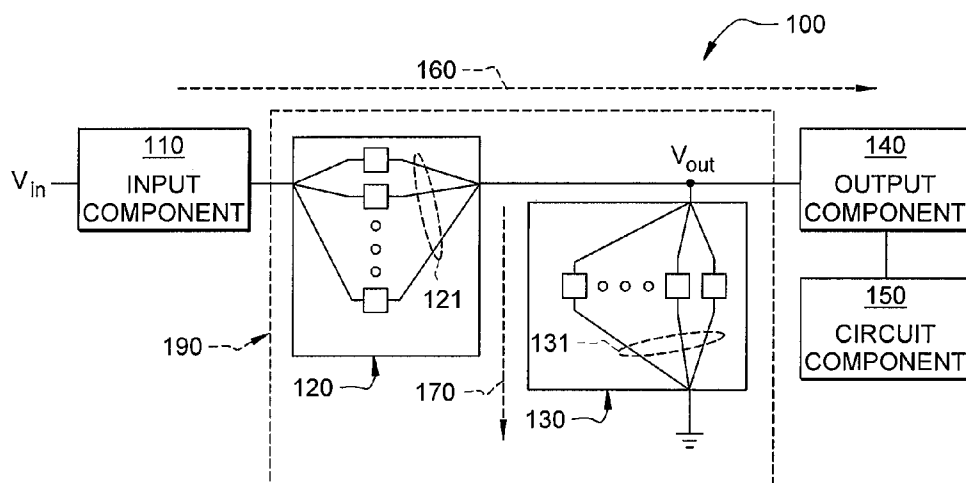


FIG. 1

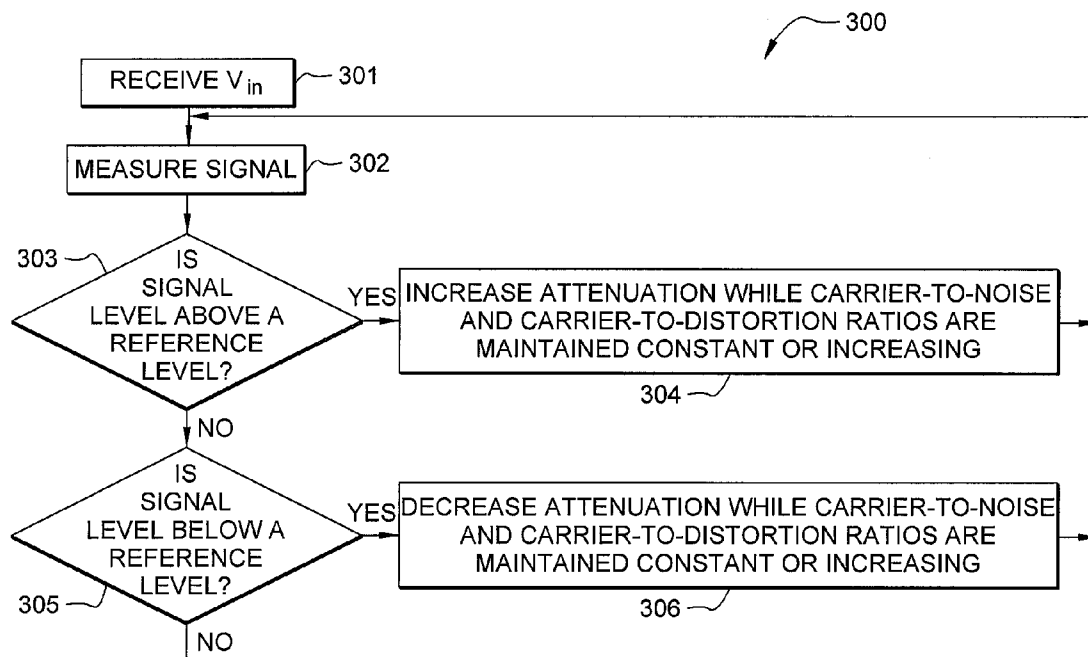
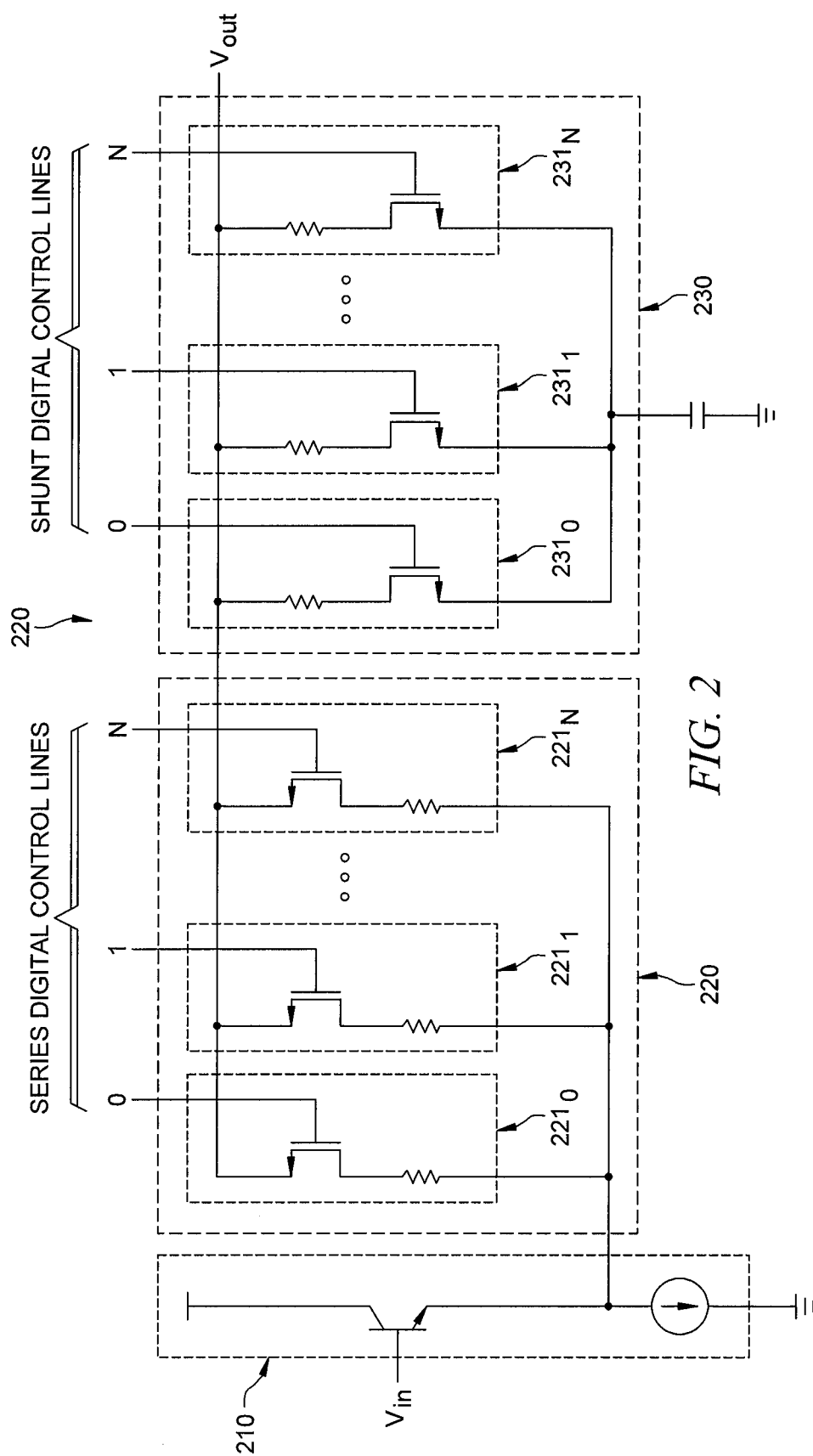


FIG. 3



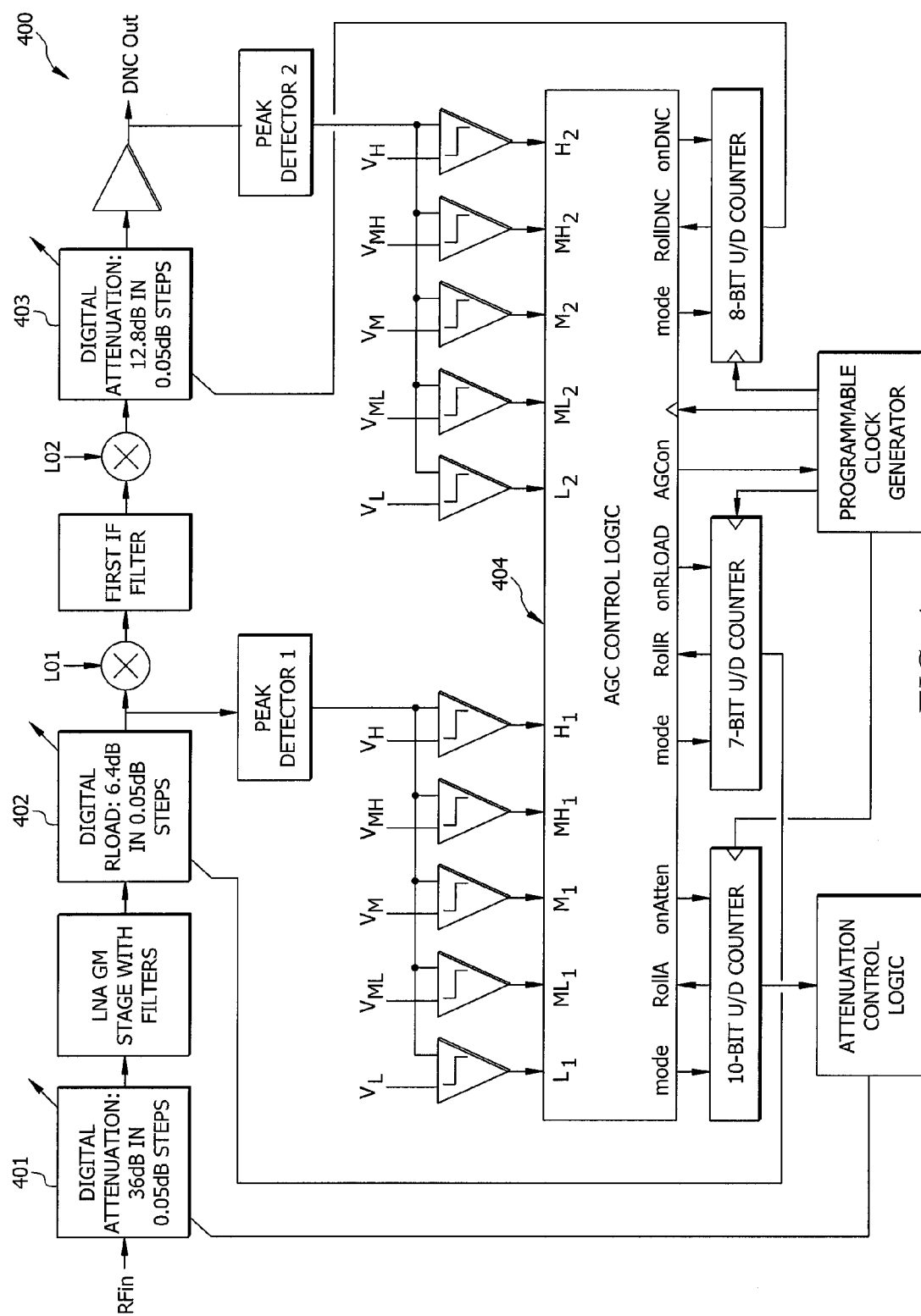


FIG. 4

AGC METHOD USING DIGITAL GAIN CONTROL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 11/442,643 filed May 26, 2006 and entitled "DIGITAL ATTENUATOR CIRCUITS AND METHODS FOR USE THEREOF," the disclosure of which is hereby incorporated herein by reference.

[0002] The present application is also related to co-pending and commonly-assigned U.S. patent application Ser. No. 11/441,816 [attorney docket no. 49581/P046US], filed May 26, 2006, entitled, "AGC SYSTEM AND METHOD FOR BROADBAND TUNERS," the disclosure of which is hereby incorporated herein by reference.

TECHNICAL FIELD

[0003] Various embodiments of the present invention relate, in general, to attenuation circuits, and more specifically, to digitally-controllable attenuation circuits.

BACKGROUND OF THE INVENTION

[0004] In prior art Radio Frequency (RF) tuners, Automatic Gain Control (AGC) is often performed at the beginning of the RF signal path before the signal is fed to distortion-causing circuitry, such as amplifiers. For instance, tuners typically maintain an output signal power level at or below a certain reference value. The reference value is usually based on an assumption that the signal power level at any point in the signal path is unlikely to drive a component "to the rails" if the output signal is at or below the reference value. Attenuation is performed on the signal input when it is determined that the output signal power level is above the reference value.

[0005] In one prior art application, analog AGC is performed inside the first amplifier itself. However, this approach is prone to distortion, since the AGC is performed inside the amplifier. Another approach is to use a pin-diode attenuator in the signal path before the distortion-causing circuitry. However, pin-diode attenuators typically cannot be built on a semiconductor chip, such that in tuner-on-chip applications, the attenuation is performed off-chip.

BRIEF SUMMARY OF THE INVENTION

[0006] Various embodiments of the present invention are directed to systems and methods for providing digitally-controllable attenuation. In one example, an attenuator circuit includes a voltage-divider arrangement with two adjustable impedance components, the second of which is shunted to ground. The attenuation is a function of the relative values of the adjustable impedance components.

[0007] In this example, each of the adjustable impedance components includes a plurality of selectable, discrete elements that each have some amount of impedance. In each adjustable impedance component, selecting one or more of the elements determines the impedance of the component. Each discrete element can be switched on or off using, e.g., a transistor that is controlled by digital control lines. Thus, digital signals from the control lines can provide a range of discrete impedance values for each impedance component. Accordingly, the attenuation of the circuit is controllable digitally.

[0008] An example method using the arrangement described above includes receiving an RF signal, and adjusting the impedances of the impedance components (and, therefore, the attenuation) based upon the signal level. The adjusting is performed, e.g., by switching one or more of the selectable elements in each of the impedance components using digital control lines. The values of each of the impedance components may be constrained by one or more requirements, including, e.g., input/output impedance values, linearity of operation, and relationships between changes in attenuation versus changes in noise and/or distortion.

[0009] An advantage of one or more embodiments is that the attenuator circuit can be implemented in a chip along with various other components of a tuner. In fact, one or more of such attenuator circuits can be placed along the RF signal path, including before the first amplifier. In such manner, attenuation can be performed on large input signals so that the actual signal level going into the first amplifier is at or below a "take over point," or other reference level.

[0010] The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims. The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages will be better understood from the following description when considered in connection with the accompanying figures. It is to be expressly understood, however, that each of the figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] For a more complete understanding of the present invention, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0012] FIG. 1 is an illustration of an exemplary system adapted according to one embodiment of the invention;

[0013] FIG. 2 is an illustration of an exemplary system adapted according to one embodiment of the invention;

[0014] FIG. 3 is an illustration of an exemplary method adapted according to one embodiment for providing AGC in a circuit, such as the system of FIG. 1 or the system of FIG. 2; and

[0015] FIG. 4 is an illustration of an exemplary system adapted according to one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0016] FIG. 1 is an illustration of exemplary system 100 adapted according to one embodiment of the invention. System 100 includes input component 110 receiving an input signal that has a voltage V_{in} , first adjustable impedance com-

ponent **120**, and second adjustable impedance component **130**, which is shunted to ground. Output voltage V_{out} at output component **140** (e.g., wire, contact, or the like), is fed to the input of circuit component **150** (e.g., amplifier, mixer, filter, or the like). First adjustable impedance component **120** may be referred to herein as a “series” component because it is in series in first current path **160** between input component **110** and output component **140**. Likewise, second adjustable impedance component **130** may be referred to herein as a “shunt” component because it is shunted. Second adjustable impedance component **130** creates second current path **170**.

[0017] Each of first and second adjustable impedance components **120** and **130** includes a plurality of selectable, discrete legs **121** and **131**, respectively, that each have some amount of impedance. Attenuation circuit **190** can be used for Automatic Gain Control (AGC) to provide V_{out} at an approximately constant signal level (i.e., 3 dB deviation or less from a reference value) by controlling the impedances of components **120** and **130**, as explained further below.

[0018] FIG. 2 is an illustration of exemplary system **200** adapted according to one embodiment of the invention. In fact, system **200** conforms to the specifications of system **100** (FIG. 1) and may be used for AGC. System **200** includes input component **210**, first adjustable impedance component **220**, and second adjustable impedance component **230**. Typically, many embodiments will use V_{out} as an input to an amplifier (not shown) or other active circuit element.

[0019] Input component **210** in this example is an emitter follower, which is used to provide a buffer between the attenuator circuit (components **220** and **230**) and circuitry on the other side of input component **210**. Emitter followers, such as shown in system **200**, may be adaptable to a number of embodiments because they generally cause minimal distortion, while providing separation between the source impedance and the input impedance of the attenuator circuit. Input component **210** is not limited to an emitter follower in various embodiments. For instance, input component **210** may simply be a wire contact receiving V_{in} or may be a source-follower arrangement, or the like.

[0020] The attenuator circuit of the embodiment of FIG. 2 is a resistor divider including series component **220** and shunt component **230**. Each adjustable impedance component **220** and **230** includes a plurality of legs (**221** and **231**, respectively) that conduct current when “turned on” by a switch, such as a Field Effect Transistor (FET), Bipolar Junction Transistor (BJT), or other type of switch. The number of “on” legs and their respective individual impedances determine the impedance of each component **220** and **230** at a given time. Thus, by selectively turning legs on or off through digital control lines, the impedances of the components, and, therefore, the attenuation of the circuit, can be controlled. The digital control lines may be connected in some embodiments to control logic, such as a feedback loop that measures signal level, distortion, and/or noise and adjusts the attenuation circuit accordingly. It should be noted, however, that in some embodiments not all legs are switchable. For example, each component **220** and **230** may include one leg **221**, **231** that is not switchable so that the current paths are closed even when no legs are switched on, thereby providing maximum impedance and preventing an open circuit. For simplification, the impedance of component **220** is referred to as Z_{ser} and the impedance of component **230** is referred to as Z_{sh} .

[0021] Typically, the impedance (Z_{in}) as seen by input component **210** is approximately equal to Z_{sh} in parallel with the

input impedance of the following stage (Z_L) plus Z_{ser} . The impedance (Z_{out}) seen by a component at V_{out} is approximately equal to Z_{sh} in parallel with the sum of Z_{sh} and the output impedance of the previous stage (Z_s). Also, the attenuation is approximately equal to the sum of Z_{sh} and Z_{ser} divided by Z_{sh} . These relations are given in equations 1, 2, and 3, wherein “approximately” is plus or minus 20 percent:

$$Z_{in} \approx Z_{ser} + Z_{sh} \parallel Z_L \quad (1)$$

$$Z_{out} \approx Z_{sh} \parallel (Z_{ser} + Z_s) \quad (2)$$

$$\text{Attenuation} \approx \frac{Z_{sh} + Z_{ser}}{Z_{sh}} \quad (3)$$

[0022] In some embodiments, it is advantageous to maintain a carrier-to-noise ratio at the output of an active element following a given attenuator approximately constant or increasing throughout the range of attenuation. The noise of interest including noise from components **220** and **230** and any active element at V_{out} such as, for example, an amplifier (not shown). Additionally, in some embodiments it is desirable to maintain a carrier-to-distortion ratio at the output of an active element following a given attenuator approximately constant or increasing throughout the range of attenuation. The distortion of interest including distortion from components **220** and **230** and any active element at V_{out} such as, for example, an amplifier (not shown).

[0023] In general, Z_{in} is maintained relatively high in some embodiments in order to minimize distortion from the emitter follower in component **210**. Also, many embodiments maintain Z_{out} relatively low in order to keep noise from the amplifier at V_{out} low. Maintaining the relationships of Z_{in} and Z_{out} may help to provide an attenuation circuit that performs similarly to the examples in FIGS. 3 and 4. The values of Z_{in} and Z_{out} may also be determined, at least in part, by impedance matching concerns with regard to adjacent circuit elements.

[0024] The high value for Z_{in} and the low value for Z_{out} depend on the specific application for which the attenuator is designed. For example, distortion caused by an emitter follower usually depends, at least in part, on the current there-through and on the impedance immediately following it—in this case, Z_{in} . Also, an amplifier will usually experience better noise reduction if its source impedance seen by its input—in this case, the output impedance of the attenuator circuit, is lower than or equal to the optimal source impedance of the amplifier. Typically, an optimal source impedance of an amplifier is specific to each amplifier and represents the impedance wherein input referred voltage noise is equal to input referred current noise multiplied by source impedance. In one specific example, a system has an amplifier input at V_{out} approximately 10 mA of current from the emitter follower of component **210**, a floor value for Z_{in} of 100 Ohms, and a ceiling value for Z_{out} of 75 Ohms.

[0025] Any given attenuation level may be achieved by a multitude of (Z_{ser} , Z_{sh}) value pairs. Appropriate (Z_{ser} , Z_{sh}) value pairs may be determined using the constraints provided by a ceiling value for Z_{out} , a floor value for Z_{in} , equations 1, 2, and 3, and the carrier-to-noise and carrier-to-distortion relationships (described above) to advantageously provide attenuation in many applications. Specifically, in one example, a control system determines a desired attenuation

level and adjusts the values of impedance components **220** and **230** to provide that attenuation level while staying within the constraints.

[0026] One advantage of some embodiments of the present invention is that the attenuator circuit can be disposed in a single semiconductor chip, thereby facilitating the production of larger single-chip or all-semiconductor systems. In fact, various embodiments may be included in chip-based RF tuners.

[0027] Returning to FIG. 2, in many embodiments, the switches in legs **221** and/or **231** of components **220** and **230** cause some amount of distortion. For example, when Metal Oxide Semiconductor (MOS) FETs are used as switches in legs **221** and/or **231**, distortion caused thereby can often be a design or operation concern. This phenomenon is more likely when Z_{ser} is high and the voltage drop is high across a particular switch in one or more legs **221**. In system **200**, each leg **221** and **231** includes a MOSFET switch and a resistor in series therewith. The ratio of resistance from the resistor and resistance from the MOSFET can be tailored for specific legs. Thus, when Z_{ser} is high, the leg or legs **221** used in component **220** can have a resistance ratio of, e.g., 80% resistor and 20% MOSFET. As more legs **221** are switched on to lower the impedance of component **220**, the resistance ratios of additional legs **221** may decrease to e.g., 50% resistor and 50% MOSFET, even as low as 100% MOSFET in a few legs **221**. Such a design may help to reduce distortion, especially in component **220**. Oftentimes, the voltage drop across component **230** will not have an appreciable affect on distortion, so resistance ratios of, e.g., 80% resistor and 20% MOSFET, can be appropriate for many, if not all, of legs **231**.

[0028] The number of legs in a given embodiment can often determine the sizes of the incremental changes in attenuation that are available from the circuit. In one example, fourteen legs **221** in component **220** and eight legs **231** in component **230** are used to provide attenuation in 0.05 dB steps over a 36 dB range. In this example, legs **221** of component **220** provide coarse adjustments in the attenuation level, while legs **231** of component **230** provide fine tuning. At minimum attenuation (Z_{ser} high, Z_{sh} low), the first few legs **221** of component **220** switch out between 0.5 dB and 1 dB attenuation increases, with legs **231** of component **230** providing fine tuning in a binary-coded manner. As attenuation increases, each leg **221** of component **220** represents a step of up to 3 dB, such that the frequency of switching in legs **221** of component **230** increases.

[0029] FIG. 3 is an illustration of exemplary method **300** adapted according to one embodiment for providing AGC in a circuit, such as system **100** (FIG. 1) or system **200** (FIG. 2). Method **300** maybe performed, for example, by a control system implemented in hardware and/or software that keeps signal levels within an acceptable range in a circuit. In step **301**, a voltage input signal is received. In step **302**, the level (e.g., power value) of the signal is measured. In one example, the signal level may be measured at one or more places, including at V_{out} or further downstream, such as at the output of an amplifier that uses V_{out} for its input.

[0030] At step **303**, it is determined from the measurement of step **302** if the signal level is above a desired level. If the signal level is above the desired level, then attenuation is increased in step **304** in order to keep the signal level close to the desired level, which in some embodiments means keeping the signal level approximately constant. Increasing the attenuation can be performed in one example by increasing

Z_{ser} of component **220** (FIG. 2) relative to Z_{sh} of component **230**. Further, the increase in attenuation in step **304** is performed so that a carrier-to-noise ratio at the output of an active element following a given attenuator is approximately constant or increasing throughout the range of attenuation. Additionally, a carrier-to-distortion ratio at the output of an active element following a given attenuator is kept approximately constant or increasing throughout the range of attenuation. Thus, distortion and noise levels are measured and accounted for when increasing attenuation.

[0031] In step **305**, it is determined if the signal level is below a desired level. If the signal level is below the desired level, then the attenuation is decreased in step **306**. Decreasing attenuation can be performed in one example, by decreasing Z_{ser} of component **220** (FIG. 2) relative to Z_{sh} of component **230**. Further, the decrease in attenuation is performed such that a carrier-to-noise ratio at the output of an active element following a given attenuator is approximately constant or increasing throughout the range of attenuation. Additionally, a carrier-to-distortion ratio at the output of an active element following a given attenuator is kept approximately constant or increasing throughout the range of attenuation. Thus, similar to step **304**, distortion and noise levels are measured and accounted for when decreasing attenuation.

[0032] In one or more embodiments, measuring, increasing, and/or decreasing are performed continuously or frequently to keep a signal level constant over a period of time or indefinitely. It should be noted that method **300** is for example only, and various embodiments are not limited to any one method of operation. For instance, although the method **300** is depicted as a series of sequential steps in FIG. 3, it is within the scope of embodiments to differ therefrom. Thus, step **301** may be performed continuously throughout method **300** rather than once, as shown, and, further, it may be performed simultaneously with other steps. Also, steps **303** and **305** may be performed as a single step that measures signal level or change in signal level and performs steps **304** and **306** accordingly.

[0033] Designers have been reluctant in prior art systems to create or use digital attenuators because the discrete steps may often cause a control system not to settle since there is usually some amount of error between the closest available step and the ideal value. Accordingly, a control system that performs method **300** may also include operations that allow it to settle at one or more discrete value as it operates continuously or frequently, such as, for example, by tolerating some amount of error.

[0034] FIG. 4 is an illustration of exemplary system **400** adapted according to one embodiment of the invention. System **400** is a gain control loop that includes three gain control blocks **401-403**. Each gain control block **401-403** is an attenuator circuit as shown in FIG. 1. System **400** uses gains control blocks **401-403** for small gain steps throughout a RF receive signal path both to control an overall signal level in the RF signal path and to control signal levels at discrete points in the RF signal path.

[0035] System **400** uses AGC control logic **404** to measure signal levels and to control gain control blocks **401-403**, as described in FIG. 3. An example operation of AGC control logic **404** is to determine an appropriate attenuation level of each one of gain control blocks **401-403**. AGC control logic **404** adjusts the values of individual impedance elements in each one of gain control blocks **401-403** by selecting specific, discrete elements to achieve the desired attenuation level,

each of the discrete elements having some amount of impedance. In this example, the values of the individual impedance elements in each one of gain control blocks **401-403** is determined, additionally, in view of constraints—a ceiling value for Z_{out} , a floor value for Z_{in} , equations 1, 2, and 3, and the carrier-to-noise and carrier-to-distortion relationships (described above). The values of the individual impedance elements may be determined by software or logic inside AGC control logic **404**.

[0036] While the embodiments described above show two adjustable impedance components, various embodiments are not limited thereto. For instance, an example configuration includes one fixed impedance component and one adjustable impedance component. Another example embodiment includes three or more adjustable impedance components. In fact, arrangements with any number of adjustable impedance components are within the scope of the invention.

[0037] Further, there is no requirement that configurations must conform to the voltage-divider design of FIGS. **1** and **2**. For instance, an R-2R ladder or other such arrangement may be used in some embodiments.

[0038] Also, while the examples in FIG. **2** shows the discrete legs as including resistors, various embodiments are not so limited. In addition to or alternatively to discrete, resistive elements, some embodiments may use reactive elements, such as capacitors and/or inductors to provide selectable impedance. In fact, reactive impedance from capacitors may be especially useful when attenuating lower frequency signals.

[0039] Various embodiments of the present invention may provide one or more advantages over prior art AGC systems. For example, some embodiments can be readily adapted for use in a semiconductor chip, thereby simplifying a tuner design and saving space compared to systems that use off-chip attenuators. Further, according to some embodiments, one or more attenuator circuits can be placed in an RF signal path, including immediately before the first amplifier in the signal path, thereby eliminating the need for AGC inside a distortion-causing amplifier. Still further, according to some embodiments, the number of selectable, discrete elements in a given adjustable impedance component is scalable and can provide nearly any desired step resolution for a given application.

[0040] Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

What is claimed is:

1. An attenuator circuit on a semiconductor chip, said attenuator circuit comprising:
 - an adjustable impedance element with a Radio Frequency (RF) input, wherein said element provides digitally-selectable impedance values in discrete steps; and
 - digital control lines providing digital signals to said adjustable impedance element, thereby adjusting the impedance thereof and attenuating a signal from said RF input.
2. The circuit of claim **1** wherein said circuit is included on a silicon chip at the input of a low-noise amplifier, said low noise amplifier also included on said silicon chip.
3. The circuit of claim **1** wherein said adjustable impedance element includes a set of parallel elements, at least one of said elements selectable by an associated transistor, each said element having an associated impedance.
4. The circuit of claim **1** further including:
 - digital control logic operable to measure a power level of said signal from said RF input and to provide said digital signals to said adjustable impedance element to achieve an attenuation based at least in part on said measured power level.
5. The circuit of claim **1** wherein said circuit is arranged as a voltage divider.

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