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**Wight**

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(54) **CHIREIX ARCHITECTURE USING LOW IMPEDANCE AMPLIFIERS**

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Wilmington, DE (US)

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**Related U.S. Patent Documents**

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**H03F 3/68** (2006.01)  
**H03F 3/217** (2006.01)

(52) **U.S. Cl.** ..... **330/124 R; 330/251**

(58) **Field of Classification Search** ..... **330/124 R,**  
**330/195, 207 A, 251**

See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

2,220,201	A	11/1940	Bliss	
2,624,041	A	12/1952	Evans	
3,170,127	A	2/1965	Cramer	
3,919,656	A *	11/1975	Sokal et al.	330/51
5,621,351	A	4/1997	Puri et al.	
6,133,788	A	10/2000	Dent	
6,285,251	B1	9/2001	Dent et al.	
6,930,547	B2 *	8/2005	Chandrasekaran et al.	330/124 R

**FOREIGN PATENT DOCUMENTS**

EP	0011464	5/1980
JP	S55-102906	8/1980
WO	08204507	12/1982

**OTHER PUBLICATIONS**

Conradi C.P. et al.; Evaluation of Lossless combiner in a LINC Transmitter, Proceedings of the 1999 IEEE Canadian conference on Electrical computer Engineering, May 9-12, 1999, pp. 105-110. PCT International Search Report dated Feb. 9, 2004.  
Sokal N.O.; Rf Power Amplifiers, Classes A through S How They Operate and When to Use Each; Electronics Industries Forum of New England, 1997, New York NY; IEEE May 6, 1997; pp. 179-252.  
JP55102906; Jieimuzu Oo Uerudon et al.; English translation abstract; Aug. 6, 1980; 1 Page.  
Stolowitz Ford Cowger LLP; Jun. 2, 2010, Related Case Listing; 1 Page.  
Sokal, N. O., *RF Power Amplifiers, Classes A through S—How they Operate, and When to Use Each*, Electronics Industries Forum of New England, 1997, Professional Program Proceedings, Boston, MA, May 6-8, 1997, New York, NY, IEEE, May 6, 1997, pp. 179-252.

\* cited by examiner

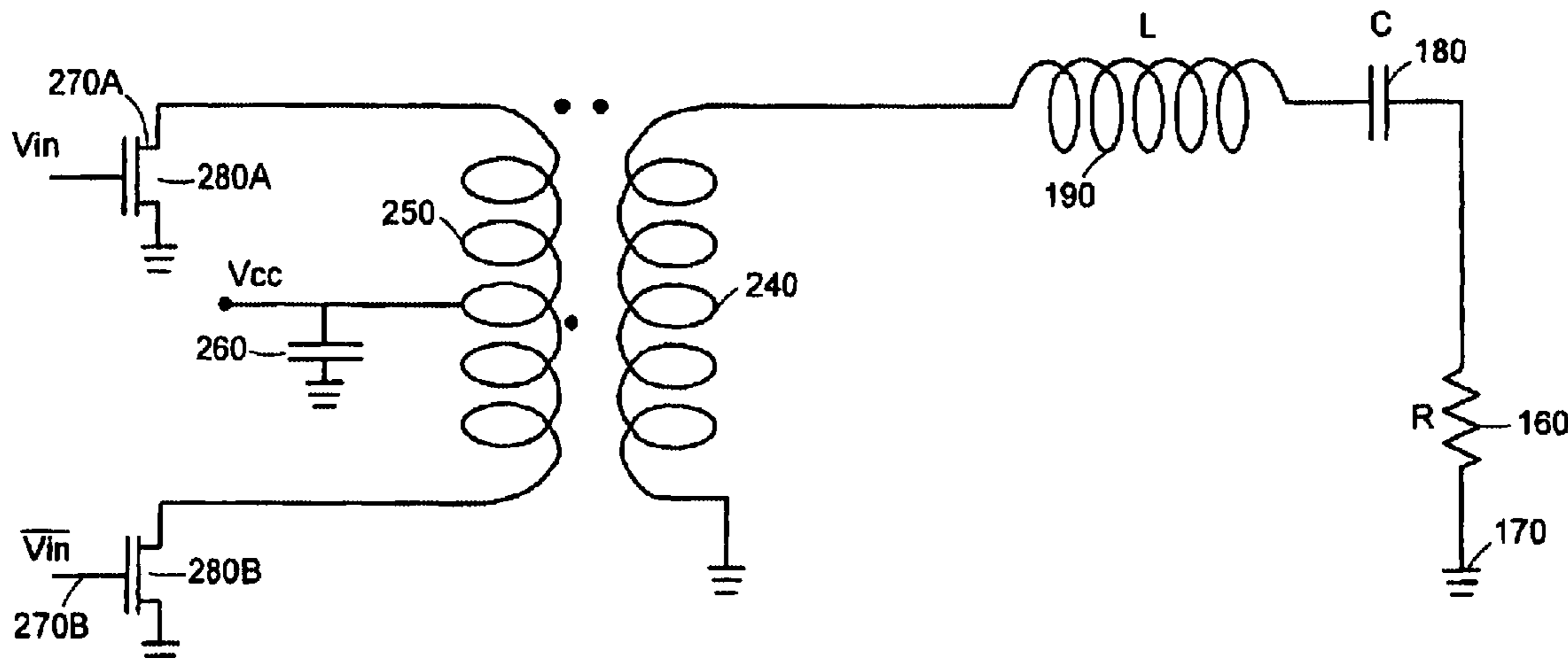
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(57) **ABSTRACT**

Circuits and methods for use in amplifying amplitude and phase modulated signals. A circuit uses a combiner with dual parallel signal amplifiers feeding it. The signal amplifiers have a low output impedance while the combiner does not provide any isolation between its inputs from the signal amplifiers. As in other Chireix architectures, the signals from the signal amplifiers are phase modulated prior to being fed to the combiner. The combiner then combines these two signals and, depending on how these two signals are combined, the resulting output of the combiner is amplitude modulated. The signal amplifiers may be Class D or Class F amplifiers to provide high efficiency amplification of the signals.

**35 Claims, 3 Drawing Sheets**



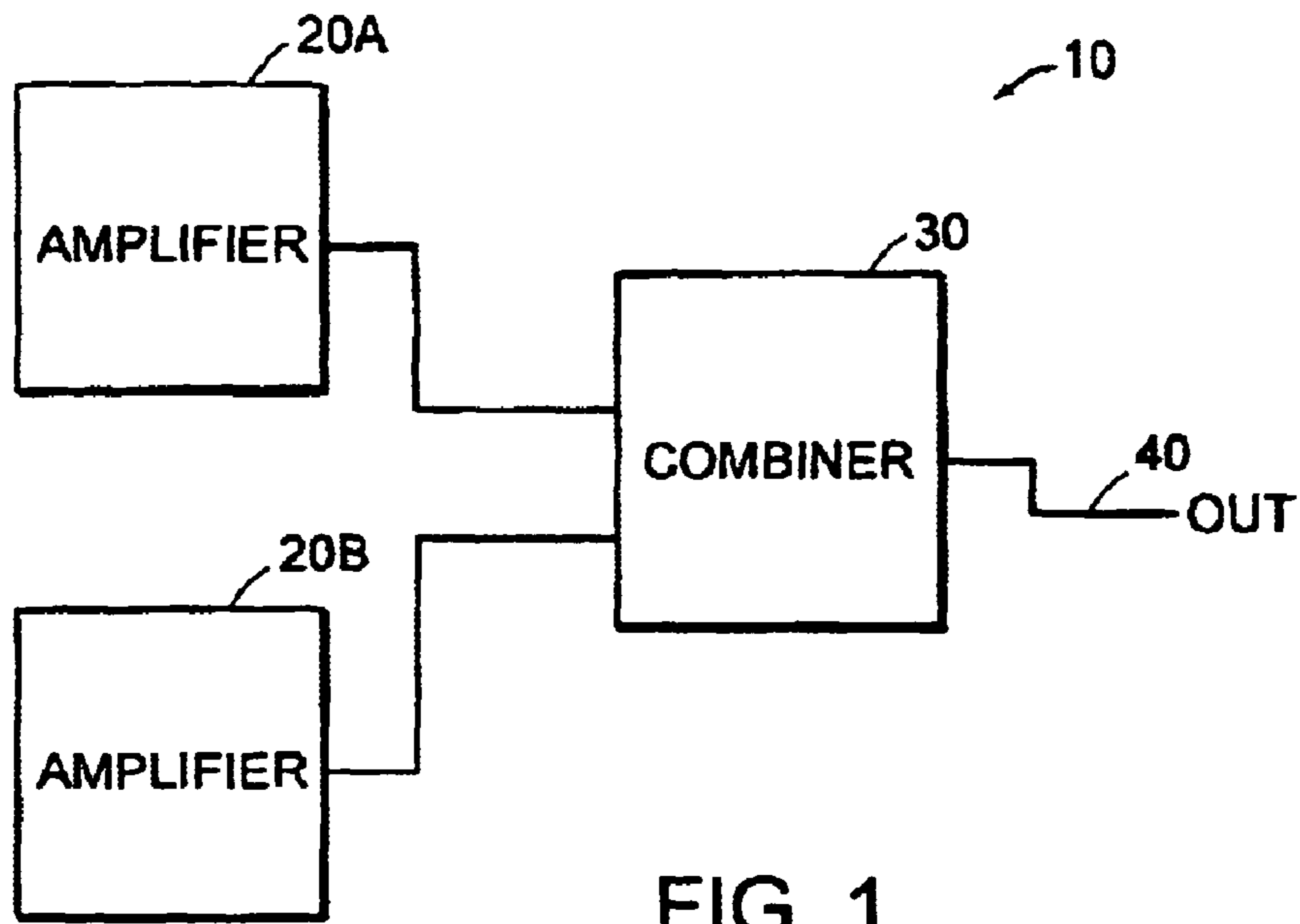


FIG. 1

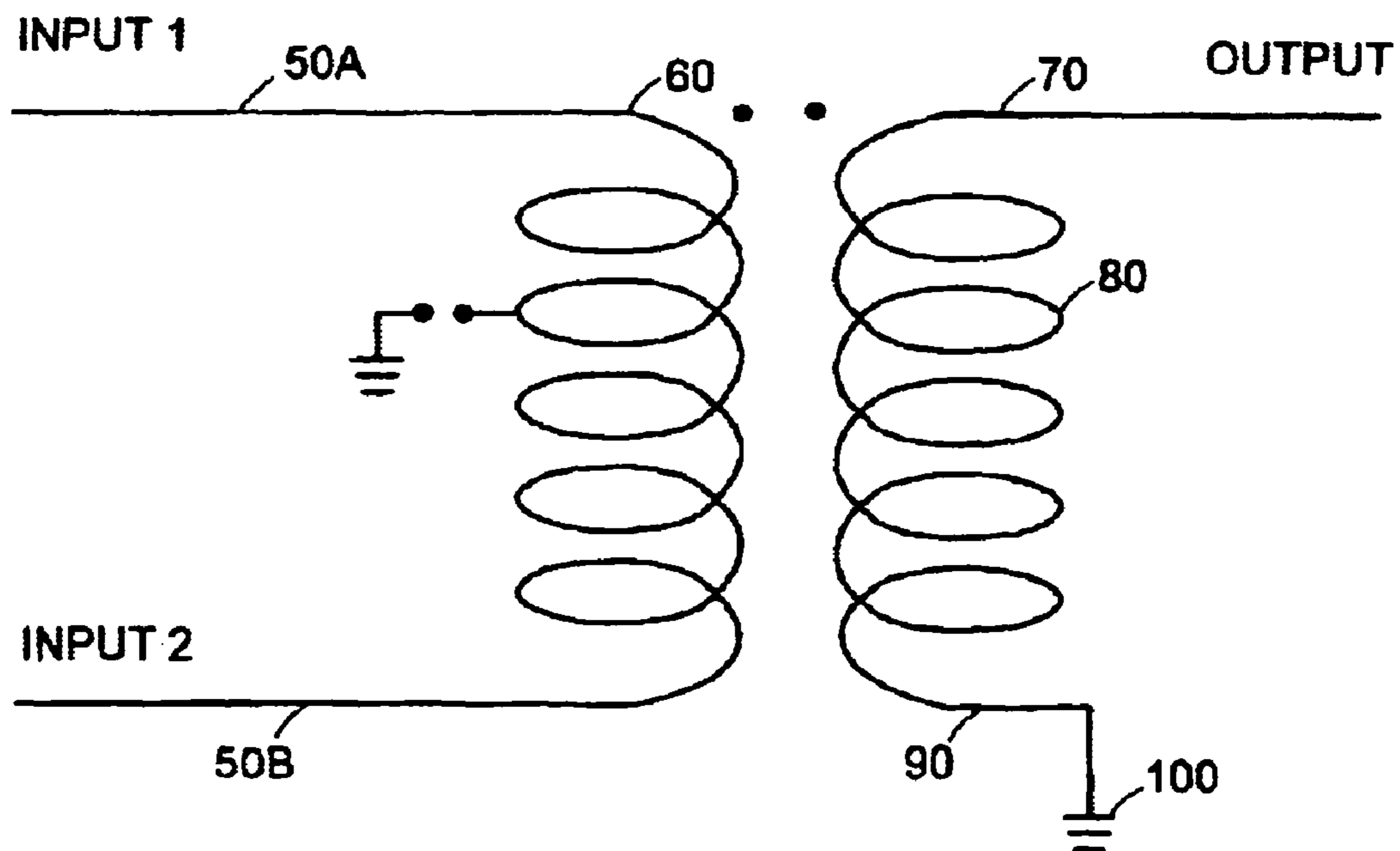


FIG. 2

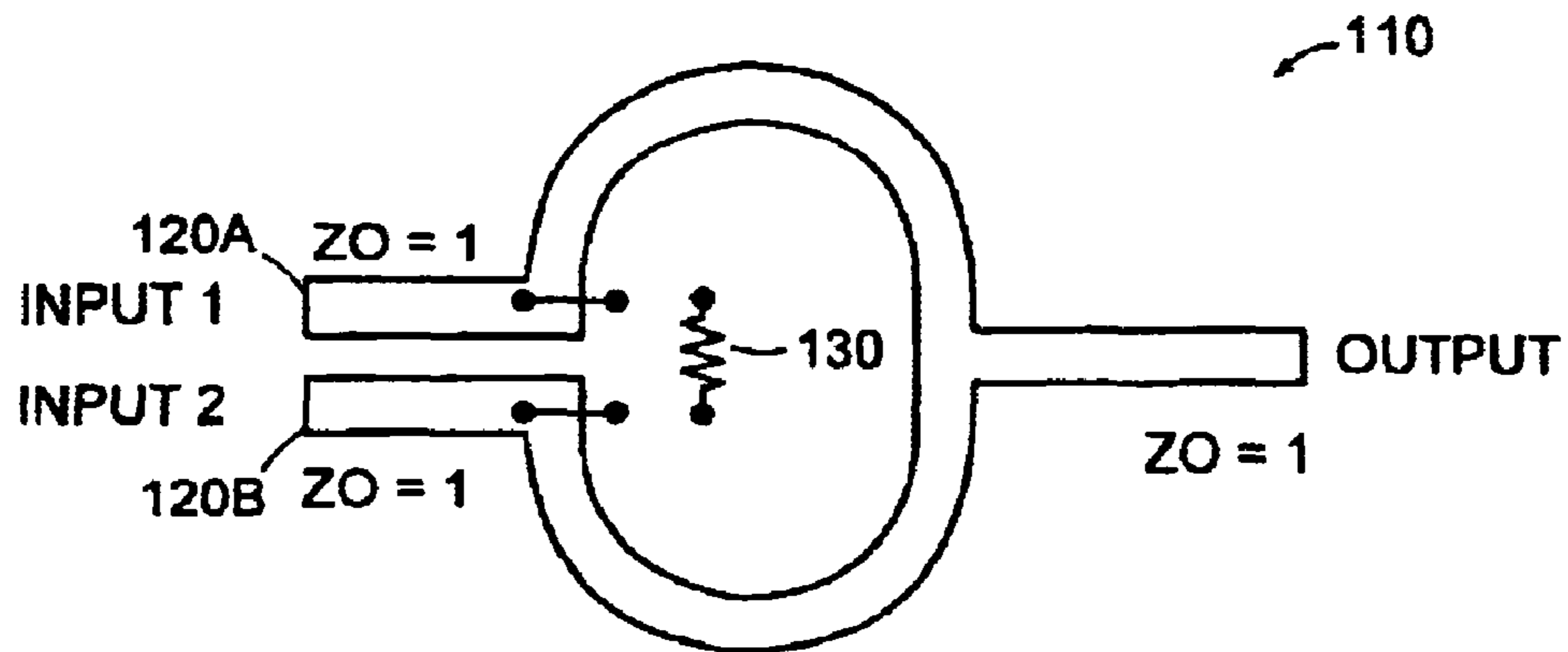


FIG. 3

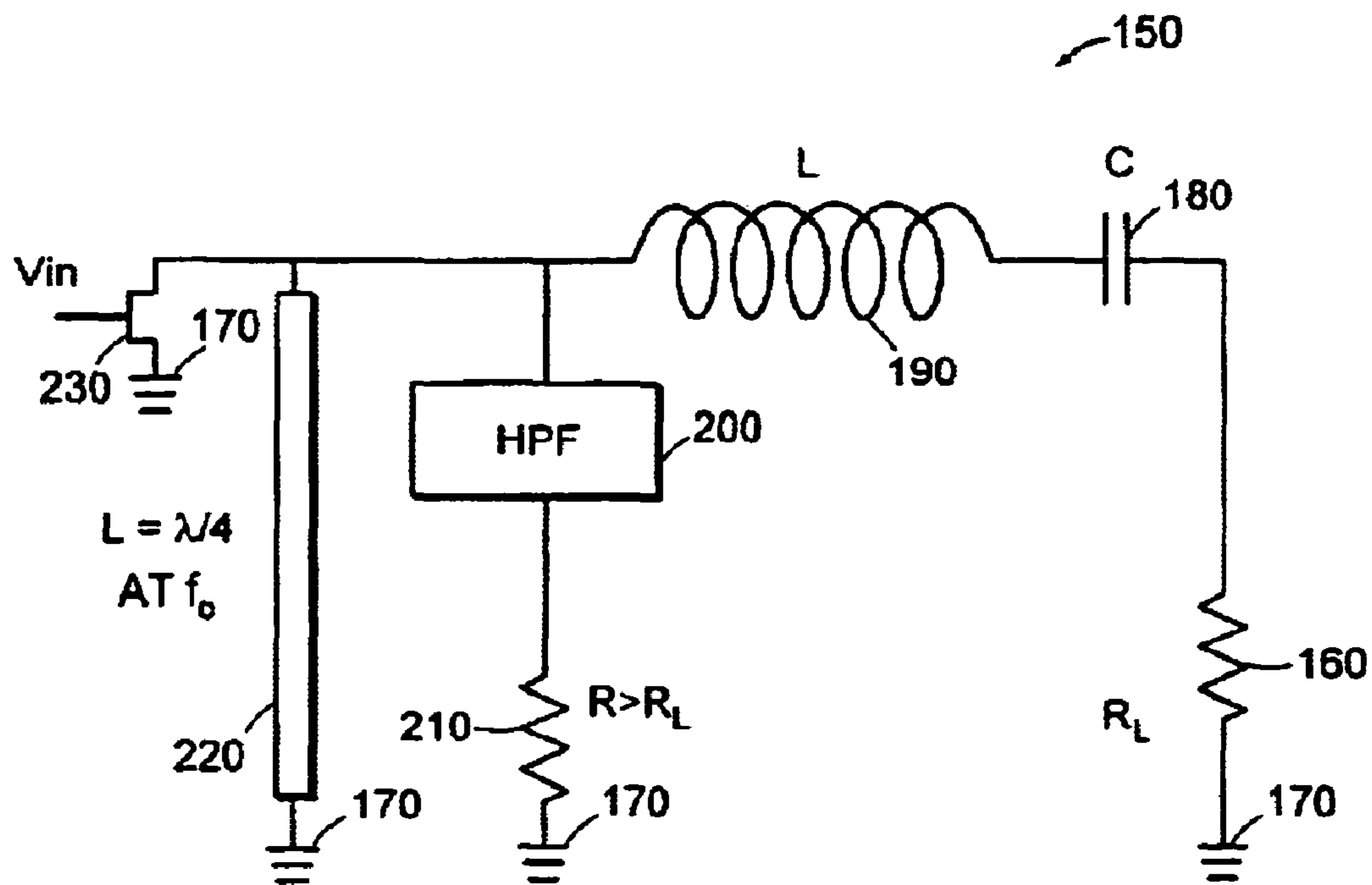


FIG. 4

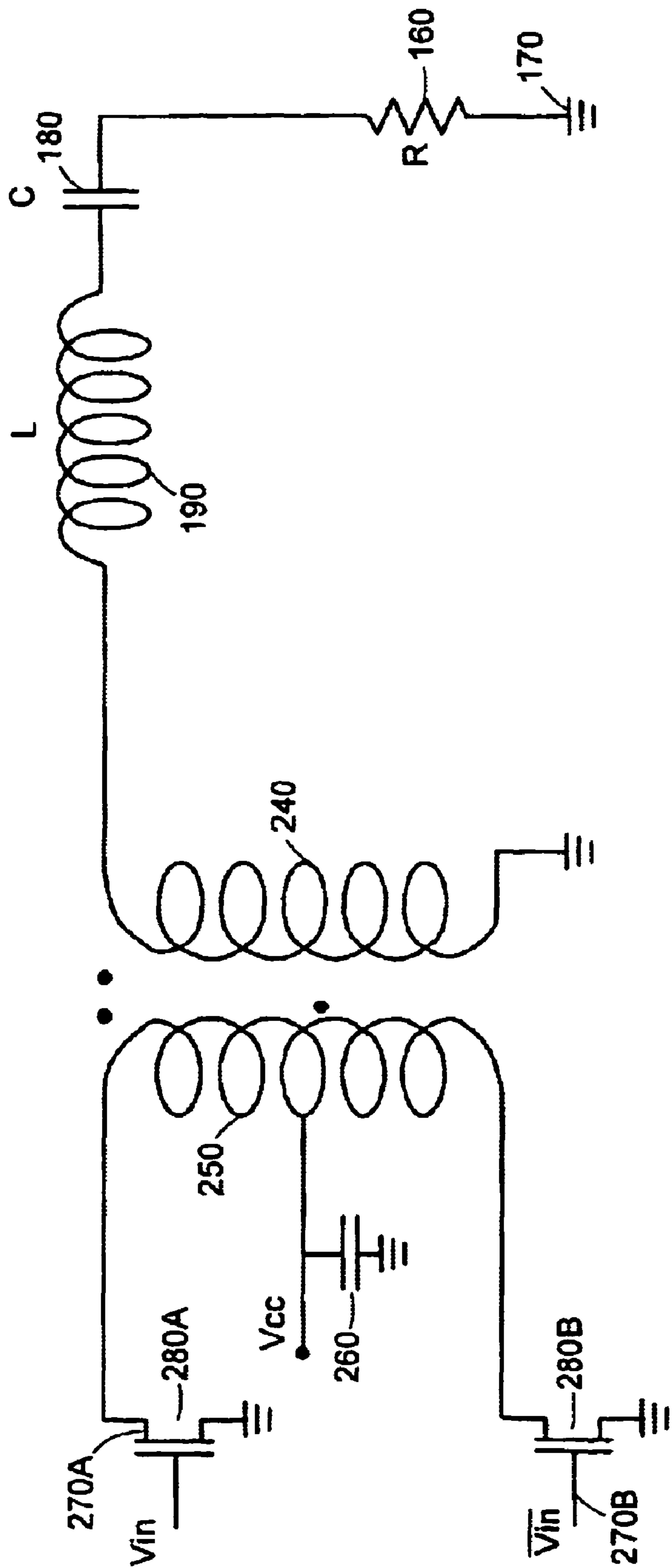


FIG. 5

## CHIREIX ARCHITECTURE USING LOW IMPEDANCE AMPLIFIERS

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.**

### FIELD OF THE INVENTION

The present invention relates to signal processing and is particularly applicable but not limited to circuits for amplifying amplitude and phase modulated signals.

### BACKGROUND TO THE INVENTION

The communications revolution of the 1990's has led to an increasing need for further and better means of transporting both data and voice communications. One offshoot of this revolution has been the burgeoning growth in wireless communications as more and more data is being transmitted by wireless means. For wireless handsets, wireless PDAs (personal digital assistants), and other wireless devices, one overarching concern is power consumption—the less power a device consumes the more desirable it is. To this end, higher efficiency components, such as amplifiers, are desirable in these wireless devices.

One type of architecture which was used in the past but has fallen out of recent favor is the so called Chireix architecture. First suggested by Henry Chireix in 1935, the technique also known as “outphasing” involves separately phase modulating two signals and recombining them in a combiner or combining network. By judiciously adjusting the phase modulation of the two signals, the combined resulting signal can become amplitude modulated as well as phase modulated. This technique enables the use of saturated amplifiers or switching amplifiers for amplitude modulated signals.

Also called “ampliphase” by the RCA Corporation when used in some of their radio transmitters, the technique has recently fallen out of favor due to its seeming inapplicability when amplifying signals. Previous attempts used common forms of linear and saturating amplifiers such as Class A and Class AB amplifiers to try and amplify the two signals prior to their being combined. Unfortunately, these efforts have yielded unacceptable results as the resulting circuits were found to be insufficiently efficient. A Chireix based architecture, if properly working with sufficient efficiency, would offer advantages in not only power consumption but in other areas as well.

Based on the above, there is a need for, methods or circuits which overcome or at least mitigate the drawback of the prior art. Such a solution should provide the advantages of a Chireix or outphasing architecture while providing sufficient amplification efficiency to be useful.

### SUMMARY OF THE INVENTION

The present invention provides circuits and methods for use in amplifying amplitude and phase modulated signals. A circuit uses a combiner with dual parallel signal amplifiers feeding it. The signal amplifiers have a low output impedance while the combiner does not provide any isolation between its inputs from the signal amplifiers. As in other Chireix architectures, the signals from the signal amplifiers are phase modulated prior to being fed to the combiner. The combiner then combines these two signals and, depending on how these

two signals are phase modulated, the resulting output of the combiner is amplitude modulated as well as phase modulated. The signal amplifiers may be Class D or Class F amplifiers to provide high efficiency amplification of the signals.

In a first aspect, the present invention provides a circuit for providing amplification to signals, the circuit comprising:

a signal combiner;

at least two signal amplifiers each receiving and amplifying a signal, said signal amplifiers being coupled in parallel to said combiner, each of said signal amplifiers acting as a voltage source and having a low output impedance,

wherein

each signal received and amplified by each of said signal amplifiers is phase modulated;

outputs of each of said signal amplifiers are added by said combiner to produce a resulting signal; and amplitude modulation and phase modulation of said resulting signal from said combiner is achieved by an addition of said outputs.

In a second aspect, the present invention provides a circuit for providing amplification to signals, the circuit comprising:

at least two signal amplifiers each receiving and amplifying a signal and each producing an amplifier output and acting as a voltage source; and

an signal combiner receiving each of said amplifier outputs in parallel, said signal combiner providing no isolation between said amplifier outputs,

wherein

each signal received and amplified by each of said signal amplifiers is phase modulated;

said amplifier outputs are added by said combiner to produce a resulting signal; and amplitude modulation of said resulting signal from said combiner is achieved by an addition of said amplifier outputs.

### BRIEF DESCRIPTION OF THE INVENTION

A better understanding of the invention will be obtained by considering the detailed description below, with reference to the following drawings in which:

FIG. 1 is a block diagram of an amplifier system using a Chireix architecture according to one aspect of the invention;

FIG. 2 is a block diagram of a modified balanced magnetic transformer which may be used as a combiner in the system of FIG. 1;

FIG. 3 is a block diagram of a modified Wilkinson combiner which may be used as a combiner in the system of FIG. 1;

FIG. 4 is a block diagram of a Class-F power amplifier which may be used as an amplifier in the system of FIG. 1; and

FIG. 5 is a block diagram of a Class-D power amplifier which may also be used as an amplifier in the system of FIG. 1.

### DETAILED DESCRIPTION

Referring to FIG. 1, a block diagram of a circuit 10 according to one aspect of the invention is illustrated. Signal amplifiers 20A, 20B feed a combiner 30 which produces an output 40. The signal amplifiers 20A, 20B are low output impedance amplifiers while the combiner 30 is a combiner appropriate for Chireix architectures.

As in well known Chireix architectures, the signals received and amplified by the signal amplifiers 20a, 20B are phase modulated signals. These phase modulated signals, after being amplified by the signal amplifiers 20A, 20B, are

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combined or added by the combiner **30** to result in the output signal **40**. By judiciously phase modulating the signals using appropriate phase modulators (not shown), the resulting signal **40** from the addition of the two signals is an amplitude modulated signal. Not only that, but the resulting signal is, in effect, an amplified version of a phase and an amplitude modulated signal.

It should be noted that similar architectures as that illustrated in FIG. **1** have been attempted in the past. However, the low efficiency of the circuitry of the previous attempts stem from their use of low efficiency amplifiers such as Class A and Class AB amplifiers which have significant output impedances. Such linear and saturating amplifiers did not respond correctly to the dynamic adjustment of the load impedance being presented to them due to their significant output impedance.

The dynamic nature of the load impedance is a result of the appropriate combiner for a Chireix architecture. Such an appropriate combiner not only reinserts the amplitude modulation to the resulting signal **40**, it also provides a dynamic adjustment of the load impedance presented to each one of the signal amplifiers. This outphasing adjustment of the load impedance is such that the DC current through each signal amplifier decreases as the combined output amplitude decreases thereby maintaining high efficiency.

Two appropriate combiners are illustrated in FIGS. **2** and **3**. FIG. **2** illustrates a modified balanced magnetic transformer. As is known in the art, magnetic transformer combiners normally have a center tap-to-ground connection. In the modified transformer of FIG. **2**, the tap-to-ground connection is not present. As can be seen, each of the two terminals **50A**, **50B** of an input winding **60** is to be coupled to a signal input or, in this case, a corresponding output of a corresponding signal amplifier. The output **70** is taken from one terminal of the output winding **80** while the other terminal **90** is coupled to ground **100**.

Another appropriate combiner is a modified Wilkinson combiner **110** as illustrated in FIG. **3**. As is known, a Wilkinson combiner has an isolating resistor which is normally coupled between the inputs. In the modified Wilkinson combiner of FIG. **3**, neither of the inputs **120A**, **120B** are coupled to the isolating resistor **130**. This isolating resistor is effectively not present in the modified combiner of FIG. **3**. The resistor **130** is provided merely for illustration. Other than this modification relating to the non-coupled resistor **130**, the modified Wilkinson combiner **110** is similar in couplings and characteristics to other well known Wilkinson combiners.

Regarding a proper choice of amplifiers for use in the block diagram of FIG. **1**, it has been found by the inventors that either Class D or Class F power amplifiers can correctly respond to the dynamic nature of the load impedance as mentioned above. These Class D or Class F power amplifiers provide the desirably very low output impedances that allows the Chireix architecture to amplify both phase and amplitude modulated signals. Such a Class F power amplifier is illustrated in FIG. **4**. This Class F amplifier **150** consists of a resistor load **160** coupled between ground **170** and a capacitor **180**. An inductor **190** also coupled in series with the capacitor **180** forms a resonator which passes the fundamental harmonic of the signal to resistor load **160**. Between the inductor **190** and ground are coupled, in series, a high pass filter **200** and another resistor **210**. The resistor **210** has a much higher resistance value than the load resistor **160**. A shorted, quarter wave transmission line **220** effectively shorts all even harmonic voltages while all odd harmonic voltages, including the fundamental, are passed on. A switching voltage input **230** is provided through a transistor **230**.

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As is known, Class F amplifiers provide a good approximation to a voltage square-wave across the output terminals of a device by "shorting" all even-harmonic voltages and "supporting" all odd-harmonic voltages. As a result, the voltage waveform across the output terminals of a device contains only odd-harmonic components. In addition, this sorting of odd- and even-harmonics results in a current passing through the output terminals of the device that contains the fundamental, and only even-harmonic components.

This "shorting" and "supporting" of harmonics is conveniently achieved with a shorted quarter-wave shunt-stub connected across the device's output terminals, as shown in FIG. **4**. The stub will "short" the even harmonics and "support" the odd harmonics. Since each harmonic will contain only a voltage component or a current component, the device will not absorb power, except at the fundamental.

In a practical situation, with a stub effectively shorting only the second harmonic voltage, and passing only the fundamental and third harmonic voltage, the power-added efficiency can be more than 85%.

As an example of a Class D amplifier which may be used with the invention, FIG. **5** illustrates a block diagram of a Class D amplifier. As can be seen, the Class D amplifier is somewhat similar in structure to the Class F amplifier of FIG. **4**. Inductor **190**, capacitor **180** and resistor load **160** form a series circuit. The inductor **190** is coupled in series with one end of a transformer coil **240** while the other end of the transformer coil **240** is coupled to ground **170**. The other transformer coil **250** is tapped by a voltage source (Vcc) coupled to a grounded capacitor **260**. This other transformer coil **250** is coupled at each end to a switching voltage input **270A**, **270B** by way of transistors **280A**, **280B**.

For such Class D (voltage switching) amplifiers, the active device passes no current between its output terminals when the voltage across its output terminals is at the voltage rail, and passes maximum current between its output terminals when the voltage across its output terminals is zero. As a result, the device does not absorb any power, and all power taken from the bias supply is converted into the output signal (100% power-added efficiency).

It should be noted that the amplifiers in the amplifier pair **20A**, **20B** in FIG. **1** are to be of the same type. As such, if one amplifier **20A** is a Class D amplifier, the other amplifier **20B** should also be a Class D amplifier. Similarly, if one amplifier is a Class F amplifier, the other should also be a Class F amplifier. These two amplifier classes provide the requisite switch mode operation along with the very low output impedance. Other amplifier classes may have the switch mode operation but their output impedance is not of the desired very low value.

It should also be noted that while the circuit of FIG. **1** only illustrates two signal amplifiers in parallel, multiple signal amplifiers may be used in parallel with an appropriate combiner. Such a configuration may use multiple parallel signal amplifiers of the same type or class, with all parallel signal amplifiers feeding a single multiple input port combiner. However, as noted above, these multiple signal amplifiers are to have the requisite switch mode operation and the low output impedance. Ideally, such a multiply parallel arrangement would only use Class D or Class F power amplifiers.

A person understanding this invention may now conceive of alternative structures and embodiments or variations of the above all of which are intended to fall within the scope of the invention as defined in the claims that follow.

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What is claimed is:

1. A circuit for providing amplification to signals, the circuit comprising:

a signal combiner, wherein said combiner is a modified balanced magnetic transformer, said transformer being devoid of a center tap to ground connection;

at least two signal amplifiers each receiving and amplifying a signal, said signal amplifiers being coupled in parallel to said combiner, each of said signal amplifiers having a low output impedance and acting as a voltage source, wherein each signal received and amplified by each of said signal amplifiers is phase modulated, *and wherein at least one of the at least two amplifiers is configured to operate as a class F amplifier;*

outputs of each of said signal amplifiers are added by said combiner to produce a resulting signal, said signal amplifier outputs being coupled to terminals of an input winding of said transformer; and amplitude modulation of said resulting signal from said combiner is achieved by an addition of said outputs.

2. A circuit according to claim 1 wherein said combiner provides minimum isolation between said outputs of said signal amplifiers.

3. A circuit according to claim 1 wherein said combiner provides no isolation between said outputs of said signal amplifiers.

4. A circuit according to claim 1 wherein each of said amplifiers has switch mode operation.

[5. A circuit according to claim 4 wherein each of said amplifiers is chosen from a group comprising:

class D signal amplifiers; and  
class F signal amplifiers.]

6. A circuit according to claim 1 wherein all of said at least two signal amplifiers are of the same type.

7. A circuit for providing amplification to signals, the circuit comprising:

at least two signal amplifiers each receiving and amplifying a *phase modulated signal* [and], each producing an amplifier output, *and at least one of the at least two signal amplifiers operating as a class F amplifier;* and a signal combiner receiving each of said amplifier outputs in parallel, said signal combiner providing no isolation between said amplifier outputs,

wherein

each signal received and amplified by each of said signal amplifiers is phase modulated;

said signal combiner is a modified balanced magnetic transformer, said transformer being devoid of a center [tan] tap to ground connection;

said amplifier outputs are added by said combiner to produce a resulting [signals] signal,

said amplifier outputs being coupled to terminals of an input winding of said transformer; and

amplitude modulation of said resulting signal from said combiner is achieved by an addition of said amplifier outputs.

[8. A circuit according to claim 7 wherein each of said signal amplifiers has a very low output impedance.]

9. A circuit according to claim [8] 7 wherein each of said signal amplifiers has switch mode operation.

[10. A circuit according to claim 9 wherein each of said signal amplifiers is chosen from a group comprising:

class D signal amplifiers; and  
class F signal amplifiers.]

[11. A circuit according to claims 7 wherein each of said signal amplifiers is chosen from a group comprising:

class D signal amplifiers; and  
class F signal amplifiers.]

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[12. A circuit according to claim 7 wherein all of said at least two signal amplifiers are of the same type.]

13. An apparatus, comprising:

at least two amplifiers each configured to amplify a corresponding phase modulated signal; and

a signal combiner configured to combine outputs of said at least two amplifiers to produce a resulting signal;

wherein said combiner includes a balanced magnetic transformer not requiring a center tap to ground;

wherein the resulting signal is configured to be amplitude modulated via the corresponding phase modulated signal amplified by each of said at least two amplifiers;

wherein at least one of the at least two amplifiers is configured to operate as a class F amplifier; and

wherein said outputs of said at least two amplifiers are configured to be coupled to terminals of an input winding of said transformer.

14. The apparatus of claim 13, wherein said combiner is configured to provide minimum isolation between the outputs of said at least two amplifiers.

15. The apparatus of claim 13, wherein said combiner is configured to provide little or no isolation between the outputs of said at least two amplifiers.

16. The apparatus of claim 13, wherein one or more of said at least two amplifiers is configured to operate in a switch mode.

17. The apparatus of claim 13, wherein all or nearly all of said at least two amplifiers include a substantially similar type of amplifier.

18. An apparatus, comprising:

at least two amplifiers configured to amplify a corresponding phase modulated signal; and

a signal combiner configured to combine outputs from said at least two amplifiers to generate a resulting signal;

wherein said signal combiner is configured to provide little or no isolation between the outputs of said at least two amplifiers;

wherein said signal combiner includes a balanced magnetic transformer not requiring a center tap to ground connection;

wherein the resulting signal is capable of being amplitude modulated via the corresponding phase modulated signal amplified by each of said at least two amplifiers;

wherein one of said at least two amplifiers is configured to operate as a class F amplifier; and

wherein said outputs of said at least two amplifiers are configured to be coupled to terminals of an input winding of said transformer.

19. The apparatus of claim 18, wherein one or more of said at least two amplifiers includes a low output impedance.

20. The apparatus of claim 18, wherein one of said at least two amplifiers includes a same or similar type of amplifier.

21. An apparatus, comprising:

means for amplifying two or more phase modulated signals; and

means for combining outputs of said means for amplifying to produce a resulting signal;

wherein said means for combining includes a balanced magnetic transformer means not requiring a center tap to ground; and

wherein the resulting signal is configured to be amplitude modulated responsive to the two or more phase modulated signals amplified by said means for amplifying;

wherein said outputs of said means for amplifying are configured to be coupled to terminals of an input winding of said transformer means; and

wherein the means for amplifying includes at least one class F amplifier.

22. The apparatus of claim 21, wherein said means for combining is configured to provide a minimum isolation between the outputs of said amplifying means.

23. The apparatus of claim 21, wherein said means for combining is configured to provide little or no isolation between the outputs of said means for amplifying.

24. The apparatus of claim 21, wherein said means for amplifying is configured to operate in a switch mode.

25. An apparatus, comprising:

means for amplifying two or more phase modulated signals; and

means for combining outputs of said means for amplifying to generate a resulting signal;

wherein said means for combining is configured to provide little or no isolation between the outputs of said means for amplifying;

wherein said means for combining includes means for changing a voltage of a varying current and does not require a center tap means to ground connection;

wherein the resulting signal is configured to be amplitude modulated via the two or more phase modulated signals amplified by said means for amplifying;

wherein said means for amplifying is configured to operate as at least one class F amplifier; and

wherein said outputs of said means for amplifying are configured to be coupled to terminals of an input winding of said means for combining.

26. The apparatus of claim 25, wherein said means for amplifying includes a low output impedance.

27. A method, comprising:

amplifying two or more phase modulated signals received at two or more amplifiers;

combining the two or more amplified signals with a balanced magnetic transformer without requiring a center tap to ground to produce a resulting signal; and

amplitude modulating the resulting signal responsive to the two or more phase modulated signals received at the two or more amplifiers;

wherein outputs of said two or more amplifiers are configured to be coupled to terminals of an input winding of said transformer; and

wherein at least one of the two or more amplifiers is configured to operate as a class F amplifier.

28. The method of claim 27, wherein said combining includes providing a minimum isolation between the two or more amplified signals.

29. The method of claim 27, wherein said combining includes providing little or no isolation between the two or more amplified signals.

30. The method of claim 27, wherein said amplifying includes operating in a switch mode.

31. A method, comprising:

amplifying two or more phase modulated signals corresponding to two or more amplifiers; and

combining the two or more amplified signals with a balanced magnetic transformer without requiring a center tap to ground to produce a resulting signal;

wherein said combining includes providing little or no isolation between the two or more signals;

wherein said amplifying includes operating the two or more amplifiers in a switch mode;

wherein said combining includes amplitude modulating the resulting signal responsive to the two or more phase modulated signals corresponding to the two or more amplifiers;

wherein outputs of said two or more amplifiers are configured to be coupled to terminals of an input winding of said transformer; and

wherein at least one of the two or more amplifiers is configured to operate as a class F amplifier.

32. The method of claim 31, wherein said amplifying includes amplifying using two or more low output impedance amplifiers.

33. A wireless device, comprising:

a baseband processor; and

a radio-frequency transmitter coupled to said baseband processor, said radio-frequency transmitter comprising: at least two amplifiers each configured to amplify a corresponding phase modulated signal; and

a signal combiner configured to combine outputs of said at least two low output impedance amplifiers to produce a resulting signal;

wherein said combiner includes a balanced magnetic transformer not requiring a center tap to ground connection;

wherein the resulting signal is capable of being amplitude modulated via the phase modulated signals corresponding to each of said at least two amplifiers;

wherein said outputs of said at least two amplifiers are configured to be coupled to terminals of an input winding of said transformer; and

wherein at least one of the at least two amplifiers is configured to operate as a class F amplifier.

34. The wireless device of claim 33, wherein said combiner is configured to provide a minimum isolation between the outputs of said at least two amplifiers.

35. The wireless device of claim 33, wherein said combiner is configured to provide little or no isolation between the outputs of said at least two amplifiers.

36. The wireless device of claim 33, wherein one or more of said at least two amplifiers is configured to operate in a switch mode.

37. The wireless device of claim 33, wherein all or nearly all of said at least two amplifiers include a same or similar type of amplifier.

38. A wireless device, comprising:

a baseband processor; and

a radio-frequency transmitter coupled to said baseband processor, comprising:

at least two amplifiers configured to amplify corresponding phase modulated signals; and

a signal combiner configured to combine outputs from said at least two amplifiers to generate a resulting signal;

wherein said signal combiner includes a balanced magnetic transformer not requiring a center tap to ground connection;

wherein the resulting signal is configured to be amplitude modulated responsive to the phase modulated signal corresponding to each of said at least two amplifiers;

wherein said outputs of said at least two amplifiers are configured to be coupled to terminals of an input winding of said transformer; and

wherein at least one of the at least two amplifiers is configured to operate as a class F amplifier.

39. The wireless device of claim 38, wherein one or more of said at least two amplifiers includes a low output impedance.

40. The wireless device of claim 38, wherein one or more of said at least two amplifiers includes a same or similar type of amplifier.



UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : RE42,447 E  
APPLICATION NO. : 11/648698  
DATED : June 14, 2011  
INVENTOR(S) : Wight

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 8, line 12, in Claim 33, delete “comprising;” and insert -- comprising: --.

Signed and Sealed this  
Eleventh Day of October, 2011

A handwritten signature in black ink that reads "David J. Kappos". The signature is written in a cursive style with a large initial "D" and "K".

David J. Kappos  
*Director of the United States Patent and Trademark Office*