CLAIMS

What is claimed is:

1. A radio frequency system comprising:

a power amplifier that outputs a radio frequency signal to a matching network via a transmission line between the power amplifier and the matching network;

a sensor monitoring the radio frequency signal and generating first sensor signals based on the radio frequency signal;

a distortion module determining a first distortion value according to at least one of (i) a sinusoidal function of the first sensor signals and (ii) a cross-correlation function of the first sensor signals; and

a first correction circuit (i) generating a first impedance tuning value based on the first distortion value and a first predetermined value, and (ii) providing feedforward control of impedance matching performed within the matching network including outputting the first impedance tuning value to one of the power amplifier and the matching network.

2. The radio frequency system of claim 1, wherein the first correction circuit comprises:

a first input module generating the first predetermined value;

a first summer summing the first distortion value and the first predetermined value to generate a first correction value; and

a tune control module generating the first impedance tuning value based on the first correction value.

3. The radio frequency system of claim 1, wherein:

the first correction circuit feeds forward the first impedance tuning value to a tune input of the matching network; and

the radio frequency system further comprises

a second distortion module determining a second distortion value based on the first sensor signals, and

a second correction circuit (i) generating a second impedance tuning value based on the second distortion value and a load setpoint value, and (ii) feeding forward the second impedance tuning value to a load input of the matching network.

4. The radio frequency system of claim 3, wherein:

the first distortion value is generated based on a dot product of the sensor signals and magnitudes of the sensor signals; and

the second distortion value is generated based on a ratio of magnitudes of the sensor signals.

5. The radio frequency system of claim 3, wherein:

the first correction circuit comprises

a first input module generating the first predetermined value,

a first summer summing the first distortion value and the first predetermined value to generate a first correction value, and

a tune control module generating the first impedance tuning value based on the first correction value; and

the second correction circuit comprises

a load setpoint module generating the load setpoint value,

a second summer summing the second distortion value and the load setpoint value to generate a second correction value, and

a load control module generating the second impedance tuning value based on the second correction value.

6. The radio frequency system of claim 3, further comprising a third correction circuit determining a third impedance tuning value based on the first distortion value and a second predetermined value,

wherein the third correction circuit outputs the third impedance tuning value to the power amplifier.

7. The radio frequency system of claim 6, wherein:

the first correction circuit comprises

a first input module generating the first predetermined value,

a first summer summing the first distortion value and the first predetermined value to generate a first correction value, and

a tune control module generating the first impedance tuning value based on the first correction value;

the second correction circuit comprises

a load setpoint module generating the load setpoint value,

a second summer summing the second distortion value and the load setpoint value to generate a second correction value, and

a load control module generating the second impedance tuning value based on the second correction value; and

the third correction circuit comprises

a second input module generating the second predetermined value,

a third summer summing the first distortion value and the second predetermined value to generate a third correction value, and

a frequency control module generating the third impedance tuning value based on the third correction value.

8. The radio frequency system of claim 1, wherein:

the first correction circuit outputs the first impedance tuning value to the matching network;

the radio frequency system further comprises a second correction circuit determining a second impedance tuning value based on the first distortion value and a second predetermined value; and

the second correction circuit outputs the second impedance tuning value to the power amplifier.

9. The radio frequency system of claim 1, wherein:

the first correction circuit outputs the first impedance tuning value to the power amplifier; and

the power amplifier generates the radio frequency signal based on the first impedance tuning value.

10. The radio frequency system of claim 9, wherein the power amplifier adjusts frequency of the radio frequency signal based on the first impedance tuning value.

11. The radio frequency system of claim 10, further comprising a power control module that regulates power of the power amplifier,

wherein the power amplifier adjusts the frequency while power of the power amplifier is regulated by the power control module to coalesce power regulation and frequency tuning.

12. The radio frequency system of claim 11, wherein the power of the power amplifier is regulated during even update interrupts of the radio frequency system, and the frequency is adjusted during odd update interrupts of the radio frequency system.

13. The radio frequency system of claim 11, wherein the first correction circuit comprises:

a frequency control module that while updating the frequency accelerates through an operating bandwidth of the RF frequency system to converge the frequency to a frequency set point associated with a maximum power transfer between the RF power system and a load.

14. The radio frequency system of claim 1, further comprising a frequency control module that provides:

a first control module response when the first distortion value is greater than a maximum value; and

a second control module response when the first distortion value is less than or equal to the maximum value.

15. The radio frequency system of claim 14, wherein:

the first control module response provides a first frequency convergence rate;

the second control module response provides a second frequency convergence rate; and

the second frequency convergence rate is quicker than the first frequency convergence rate.

16. The radio frequency system of claim 1, further comprising the matching network, wherein the matching network matches an impedance of a load on the power amplifier with an impedance of the transmission line.

17. The radio frequency system of claim 16, wherein the matching network comprises:

a second sensor monitoring the radio frequency signal and generating second sensor signals; and

an impedance matching circuit matching impedance matching the load on the power amplifier with the impedance of the transmission line based on the second sensor signals.

18. The radio frequency system of claim 17, wherein the second sensor is separate from the first sensor.

19. The radio frequency system of claim 1, wherein:

the first sensor signals include a voltage signal and a current signal;

the voltage signal indicates a voltage of the radio frequency signal; and

the current signal indicates a current of the radio frequency signal.

20. The radio frequency system of claim 19, wherein the sinusoidal function includes a dot product of the voltage signal and the current signal, a magnitude of the voltage signal, and a magnitude of the current signal.

21. The radio frequency system of claim 1, wherein:

the first sensor includes a directional coupler sensor detecting a reverse power reflected back from the matching network to the power amplifier; and

the radio frequency system further comprises a second directional coupler sensor detecting a forward power provided to the transmission line by the power amplifier.

22. The radio frequency system of claim 21, wherein the sinusoidal function includes a dot product of the reverse power and the forward power, a magnitude of the reverse power, and a magnitude of the forward power.

23. A method of operating a radio frequency system comprising:

generating a radio frequency signal via a power amplifier;

outputting the radio frequency signal to a matching network via a transmission line between the power amplifier and the matching network;

monitoring the radio frequency signal and generating sensor signals based on the radio frequency signal;

determining a first distortion value according to at least one of (i) a sinusoidal function of the sensor signals and (ii) a cross-correlation function of the sensor signals;

generating a first impedance tuning value based on the first distortion value and a first predetermined value; and

providing feedforward control of impedance matching performed within the matching network including outputting the first impedance tuning value to one of the power amplifier and the matching network.

24. The method of claim 23, wherein:

the first impedance tuning value is fedforward to a tune input of the matching network; and

the method further comprises

determining a second distortion value based on a ratio of magnitudes of the sensor signals,

generating a second impedance tuning value based on the second distortion value and a load setpoint value, and

feeding forward the second impedance tuning value is outputted to a load input of the matching network,

wherein the first distortion value is determined based on a dot product of the sensor signals and magnitudes of the sensor signals.

25. The method of claim 23, further comprising:

outputting the first impedance tuning value to the power amplifier; and

adjusting frequency of the radio frequency signal via the power amplifier based on the first impedance tuning value.

CLAIMS

What is claimed is:

1. A radio frequency system comprising:

a power amplifier that outputs a radio frequency signal to a matching network via a transmission line between the power amplifier and the matching network;

a first sensor monitoring the radio frequency signal and generating first sensor signals based on the radio frequency signal;

a distortion module determining a first distortion value according to at least one of (i) a sinusoidal function of the first sensor signals and (ii) a cross-correlation function of the first sensor signals; and

a first correction circuit (i) generating a first impedance tuning value based on the first distortion value and a first predetermined value, and (ii) providing feedforward control of impedance matching performed within the matching network including outputting the first impedance tuning value to one of the power amplifier and the matching network.

2. The radio frequency system of claim 1, wherein the first correction circuit comprises:

a first input module generating the first predetermined value;

a first summer summing the first distortion value and the first predetermined value to generate a first correction value; and

a tune control module generating the first impedance tuning value based on the first correction value.

3. The radio frequency system of claim 1, wherein:

the first correction circuit feeds forward the first impedance tuning value to a tune input of the matching network; and

the radio frequency system further comprises:

a second distortion module determining a second distortion value based on the first sensor signals, and

a second correction circuit (i) generating a second impedance tuning value based on the second distortion value and a load setpoint value, and (ii) feeding forward the second impedance tuning value to a load input of the matching network.

4. The radio frequency system of claim 3, wherein:

the first distortion value is generated based on a dot product of the first sensor signals and magnitudes of the first sensor signals; and

the second distortion value is generated based on a ratio of magnitudes of the first sensor signals.

5. The radio frequency system of claim 3, wherein:

the first correction circuit comprises:

a first input module generating the first predetermined value,

a first summer summing the first distortion value and the first predetermined value to generate a first correction value, and

a tune control module generating the first impedance tuning value based on the first correction value; and

the second correction circuit comprises:

a load setpoint module generating the load setpoint value,

a second summer summing the second distortion value and the load setpoint value to generate a second correction value, and

a load control module generating the second impedance tuning value based on the second correction value.

6. The radio frequency system of claim 3, further comprising a third correction circuit determining a third impedance tuning value based on the first distortion value and a second predetermined value,

wherein the third correction circuit outputs the third impedance tuning value to the power amplifier.

7. The radio frequency system of claim 6, wherein:

the first correction circuit comprises:

a first input module generating the first predetermined value,

a first summer summing the first distortion value and the first predetermined value to generate a first correction value, and

a tune control module generating the first impedance tuning value based on the first correction value;

the second correction circuit comprises:

a load setpoint module generating the load setpoint value,

a second summer summing the second distortion value and the load setpoint value to generate a second correction value, and

a load control module generating the second impedance tuning value based on the second correction value; and

the third correction circuit comprises:

a second input module generating the second predetermined value,

a third summer summing the first distortion value and the second predetermined value to generate a third correction value, and

a frequency control module generating the third impedance tuning value based on the third correction value.

8. The radio frequency system of claim 1, wherein:

the first correction circuit outputs the first impedance tuning value to the matching network;

the radio frequency system further comprises a second correction circuit determining a second impedance tuning value based on the first distortion value and a second predetermined value; and

the second correction circuit outputs the second impedance tuning value to the power amplifier.

9. The radio frequency system of claim 1, wherein:

the first correction circuit outputs the first impedance tuning value to the power amplifier; and

the power amplifier generates the radio frequency signal based on the first impedance tuning value.

10. The radio frequency system of claim 9, wherein the power amplifier adjusts frequency of the radio frequency signal based on the first impedance tuning value.

11. The radio frequency system of claim 10, further comprising a power control module that regulates power of the power amplifier,

wherein the power amplifier adjusts the frequency while power of the power amplifier is regulated by the power control module to coalesce power regulation and frequency tuning.

12. The radio frequency system of claim 11, wherein the power of the power amplifier is regulated during even update interrupts of the radio frequency system, and the frequency is adjusted during odd update interrupts of the radio frequency system.

13. The radio frequency system of claim 11, wherein the first correction circuit comprises:

a frequency control module that while updating the frequency accelerates through an operating bandwidth of the radio frequency system to converge the frequency to a frequency set point associated with a maximum power transfer between the radio frequency power system and a load.

14. The radio frequency system of claim 1, further comprising a frequency control module that provides:

a first control module response when the first distortion value is greater than a maximum value; and

a second control module response when the first distortion value is less than or equal to the maximum value.

15. The radio frequency system of claim 14, wherein:

the first control module response provides a first frequency convergence rate;

the second control module response provides a second frequency convergence rate; and

the second frequency convergence rate is quicker than the first frequency convergence rate.

16. The radio frequency system of claim 1, wherein the matching network matches an impedance of a load on the power amplifier with an impedance of the transmission line.

17. The radio frequency system of claim 16, wherein the matching network comprises a:

matching network matching impedance of the load on the power amplifier with the impedance of the transmission line.

18. The radio frequency system of claim 1, wherein:

the first sensor signals include a voltage signal and a current signal;

the voltage signal indicates a voltage of the radio frequency signal; and

the current signal indicates a current of the radio frequency signal.

19. The radio frequency system of claim 18, wherein the sinusoidal function includes a dot product of the voltage signal and the current signal, a magnitude of the voltage signal, and a magnitude of the current signal.

20. The radio frequency system of claim 1, wherein:

the first sensor includes a directional coupler sensor detecting a reverse power reflected back from the matching network to the power amplifier; and

the radio frequency system further comprises a second directional coupler sensor detecting a forward power provided to the transmission line by the power amplifier.

21. The radio frequency system of claim 20, wherein the sinusoidal function includes a dot product of the reverse power and the forward power, a magnitude of the reverse power, and a magnitude of the forward power.

22. The radio frequency system of claim 17, further comprising a second sensor monitoring the radio frequency signal and generating second sensor signals.

23. The radio frequency system of claim 22, wherein the matching network matches impedance of the load on the power amplifier with the impedance of the transmission line based on the second sensor signals.

24. The radio frequency system of claim 23, wherein the second sensor is separate from the first sensor.

25. The radio frequency system of claim 1, wherein the radio frequency signal is a continuous or a pulsed signal.

26. The radio frequency system of claim 25, wherein at least one initial condition is determined in accordance with an edge of the radio frequency pulsed signal.

27. The radio frequency system of claim 1, further comprising a variable element to provide a variable impedance.

28. The radio frequency system of claim 27, wherein the variable impedance includes an initial value.

29. The radio frequency system of claim 27, wherein the variable element is capacitive element.

30. The radio frequency system of claim 29, wherein the capacitive element includes an initial value.

31. The radio frequency system of claim 27, wherein the variable element is a frequency control circuit.

32. The radio frequency system of claim 31, wherein the variable impedance includes an initial value.

33. The radio frequency system of claim 1, wherein tuning is responsive to a dynamic load condition.

34. The radio frequency system of claim 1, wherein control parameters are selected in response to a dynamic load condition.

35. The radio frequency system of claim 1, wherein tuning occurs within a predetermined time period.

36. The radio frequency system of claim 13, wherein frequency set point is variable.

37. A method of operating a radio frequency system comprising:

generating a radio frequency signal via a power amplifier;

outputting the radio frequency signal to a matching network via a transmission line between the power amplifier and the matching network;

monitoring the radio frequency signal and generating sensor signals based on the radio frequency signal;

determining a first distortion value according to at least one of (i) a sinusoidal function of the sensor signals and (ii) a cross-correlation function of the sensor signals;

generating a first impedance tuning value based on the first distortion value and a first predetermined value; and

providing feedforward control of impedance matching performed within the matching network including outputting the first impedance tuning value to one of the power amplifier and the matching network.

38. The method of claim 37, wherein:

the first impedance tuning value is fed forward to a tune input of the matching network; and

the method further comprises:

determining a second distortion value based on a ratio of magnitudes of the sensor signals,

generating a second impedance tuning value based on the second distortion value and a load setpoint value, and

feeding forward the second impedance tuning value is outputted to a load input of the matching network,

wherein the first distortion value is determined based on a dot product of the sensor signals and magnitudes of the sensor signals.

39. The method of claim 37, further comprising:

outputting the first impedance tuning value to the power amplifier; and

adjusting frequency of the radio frequency signal via the power amplifier based on the first impedance tuning value.