Chapter 19A

Additional Experimental Evidence Proving Existence of Conjugate Match and Non-Dissipative Source Resistance In RF Power Amplifiers

Sec 19A.1 Introduction

We learned in Chapter 19 that Warren Bruene, W5OLY, introduced a new definition of the conjugate match, which says that for the conjugate match to exist, R_L must equal R_S, where R_S is the term for the dynamic plate resistance looking upstream of the pi-network, and R_L is the resistance looking into the resonant pi-network[142]. Bruene calls R_S the 'source resistance'. According to this definition a conjugate match cannot exist when the source of power is an RF power amplifier. However, this definition is **invalid** and unsupported in any engineering text book. Material in Chapter 19 presents evidence **proving** the definition invalid.

According to the invalid definition, for a conjugate match to exist requires that $R_L = R_S$, which is not true. This definition assumes incorrectly that R_S is the source resistance. In general, R_S is greater than R_L, because plate current is zero for a portion of the cycle. Therefore, it is true there can be no conjugate match at the **input** of the pi-network. However, this (in)equality relates only to the conditions at the **input** to the pi-network tank circuit, because the effect of energy storage of the pi-network tank circuit isolates the non-linear conditions at the network input from the **output** of the pi-network, allowing the voltage-current relationship E/I at the output to be linear, thus supporting the conjugate match at the output.

Furthermore, the **true** source resistance of the RF power amplifier is the resistance looking rearward toward the plate from the input of the pi-network that we shall call R_{LP}, not R_S. Maximum available power is delivered into the pi-network tank circuit when the input resistance R_L of the pi-network at resonance equals R_{LP}, not R_S. $R_L = \frac{e_p}{i_p}$, where e_p = peak RF fundamental plate voltage, and i_p = peak RF fundamental plate current during the conditions where the minimum RF plate voltage and maximum grid voltage are equal, the condition for delivering the maximum power into the load. R_L is represented by the slope of the load line, which can be determined using the Chaffee Analysis as described in Chapter 19.

However, the true **output source resistance** is a resistance we will call R_{OS} = E/I, the time-unvarying, linear voltage-current ratio that occurs at the output of the network when the external load resistance $R_{LOAD} = R_{OS}$, and when the network is designed to transform resistance R_{OS} at the network output to resistance R_L at the input. Therefore, R_{OS} is the correct resistance for use in the definition of the conjugate match, not R_S.

Consequently, the equality required for the conjugate match to exist in the RF power amplifier is $R_{LOAD} = R_{OS}$, (not $R_L = R_S$), where R_{LOAD} is the load resistance external to the output pi-network. Thus, contrary to the new incorrect definition, it is evident that there **can** be a conjugate match at the **output** of an RF power amplifier, while not at the input.

Sec 19A.2 The Maximum Power-Transfer Theorem

Before continuing it may be helpful in appreciating the conjugate match to remind ourselves of the meaning of the Maximum Power-Transfer Theorem, and its relation to conjugate matching, as stated by Everitt[17]:

The maximum power will be absorbed by one network from another joined to it at two terminals, when the impedance of the receiving network is varied, if the impedances looking into the two networks are conjugates of each other.

A corollary of this theorem is that *there is a conjugate match if the delivery of power decreases when the receiving impedance (the load) is either increased or decreased*.

It should be understood that this corollary is practiced whenever an RF power amplifier loading is being adjusted for delivery of all available power at any given drive level. This means that the amplifier is power limited at that drive level, and that when conjugately matched to its load, all available power is delivered to the load. In addition, when the load is initially adjusted to receive all the available power at the saturation level (when minimum plate voltage equals maximum grid voltage), output source resistance R = E/I increases slightly with decreasing RF grid-drive voltage. From an academic viewpoint this increase in resistance will cause a slight deviation from the perfect conjugate match that existed when the source and load resistances were equal at the saturation level of grid drive.

However, in practice, the shape of the peak of the output-power curve with a small change in either the source resistance or the load resistance is so broad as to have little significance in the delivery of the available power at any given drive level relative to that delivered at the saturation level, where a conjugate match exists when all available power is being delivered to the load. As an example, for a – 10% change in source resistance we get an **increase** of 0.012 dB in power delivered; for a +10% change we get a **reduction** of 0.012 dB in power delivered. Even for +/– 20% changes in source resistance we get corresponding changes of only 0.054 dB in power delivered. My measurements have shown that with power amplifiers using a pair of 6146 tubes in the output, when the drive level and load have been adjusted to deliver maximum power at 100 watts, the increase in source resistance is approximately 10 percent when the grid drive is reduced to deliver 25 watts. Consequently, when viewing the power-output meter while tuning and loading the transceiver for maximum delivery of power into a 50-ohm load, it's practically impossible to adjust the source resistance closer to 50 ohms than anywhere between 45 to 55 ohms (+/–10%), because it's impossible to detect a 0.012 dB change in the meter reading. In terms of lost power when considering a deviation from a perfect conjugate match, this amount of change is insignificant.

Sec 19A.3 Non-dissipative Source Resistance

Chapter 19 also presents evidence that the output source resistance of the RF power amplifier is non-dissipative. This new Chapter 19A provides further evidence of this condition by reporting additional data resulting from measurements performed subsequent to those reported in Chapter 19. However, before presenting this new evidence, the relationship between R_{LP}, R_L and R_S needs to be put into a clear perspective that will further clarify why Bruene's new definition of the conjugate match is invalid. We will also correct an error appearing in Chapter 19 saying that 'R_S' is erroneous, by presenting a clear definition of the term as we proceed. This explanation is in addition to ignoring the effect of energy storage in the pi-network tank.

Sec 19A.4 Examining R_P, R_S, R_{LP} and R_L

As stated earlier, the new definition is invalid because it states incorrectly that a conjugate match can exist only when $R_L = R_S$, where R_L is the load resistance appearing at the input of the pi-network, and R_S is the effective plate resistance relative to a given angle θ of plate-current conduction. We know that resistance R_P is the traditional term for plate resistance, but is not always correctly considered the **source** resistance of the tube. However, the nature of R_P relative to RF amplifiers needs to be clearly understood to appreciate its effect on the operation of RF power amplifiers. We know that as plate voltage increases (or decreases), plate current increases (or decreases) accordingly, as in a resistor. However, we need to understand why plate resistance R_P is unlike a physical resistor, but is a dynamic, non-dissipative, **AC** resistance, contributing to no loss of power to heat in the tube as the tube converts DC power into AC power. It must also be understood that the cathode-to-plate resistance R_{PD} in the tube that does dissipate energy to heat, is completely separate from resistance R_P, and that the dissipation to heat results only from the kinetic energy released as the electrons bombard the plate. The product of the instantaneous cathode-to-plate voltage and the instantaneous plate current determines the amount of the energy converted to heat.

Now back to R_P. When an AC voltage is applied to the grid of a tube, it causes a corresponding change in plate current. However, resistance R_P causes a change in only the AC component of plate current resulting from a change in the AC component of plate voltage; i.e., an increase in the AC component of plate voltage causes a proportional increase in the AC component of plate current, and vice versa. Evidently, resistance R_P is not a resis**tor,** but a simple mathematical ratio: $R_P = \Delta E_P \div \Delta I_P$.

We know that a mathematical ratio cannot dissipate power, so to illustrate the effect of R_P in the operation of the RF power amplifier we will consider it in association with the load resistance presented by a resonant tank circuit in series with the plate circuit. While plate current increases with an increase in plate voltage, we know that plate current also increases with a positive increase in grid voltage. But as current through the load increases with grid voltage, plate voltage decreases, due to the voltage drop across the load resistance. Consequently, while the plate voltage is decreasing, the effect of resistance R_P tends to reduce the plate current, preventing it from increasing to the level it would if R_P didn't exist. The effect of the decrease in plate voltage on plate current is that of negative feedback. The power lost due to the decrease in plate current is not power that is dissipated, but only power that was not developed in the first place due to the lower current. Indeed, the power lost due to R_P can be compensated by simply increasing the grid drive to restore the plate current to the value it would have been in the absence of R_P.

Now we'll examine the relationship between R_P and R_S. R_S is the effective R_P when the conduction angle θ of the plate current is less than 360°. When conduction angle θ is 360°, as in Class A operation, $R_S = R_P$. However, when angle θ is less than 360°, resistance R_S increases proportionately, because the plate current is flowing for a shorter time, at times being zero. For example, when conduction angle θ = 180° $R_S = 2R_P$, because plate current is zero half of the time. But it will be helpful in perceiving the basis for our present problem to know the general expression for determining R_S relative to R_P for any value of θ. We first let $R_S = \beta R_P$, where $\beta = \frac{\pi}{\theta_1 - \sin\theta_1 \cos\theta_1}$, and where θ_1 is expressed in radians[159]. In determining the value of β, the half angle of θ is used, where $\theta/2 = \theta_1$, the angular extension of the conduction period on either side of the peak of the grid voltage and plate current.

In the example above, where θ = 180°, it is obvious that the half angle of θ is θ_1 = 90°. Thus, in solving the example in the above equation we get $\theta_1 = 1.570797$ (radian equivalent of 90°), $\sin\theta_1 = 1.0$, and $\cos\theta_1 = 0$. Because $\cos\theta_1 = 0$, the right-hand term of the denominator in the above equation is zero, reducing the equation to

$$\beta = \frac{\pi}{\theta_1} = \frac{3.141593...}{1.570797...} = 2,$$

proving that $R_S = 2R_P$ when the conduction angle is 180°.

Now we present a more detailed explanation why the definition requiring that $R_L = R_S$ for a conjugate match to exist when the source is an RF power amplifier is invalid. To avoid confusion we must first be clear on how we view resistances R_{LP} and R_L. R_{LP} is the resistance looking rearward from the network input toward the plate, dependent on the following four independent variables: the DC plate voltage E_B; the DC grid bias E_C; the AC component of the grid voltage Eg (the input signal voltage); angle θ representing the period of the conduction of plate current; and the AC plate voltage E_{LC}, the voltage appearing across the input to the LC pi-network tank circuit. It is important to know that there is a single value of R_{LP} for each useful combination of these independent variables. (As stated earlier, the optimum R_{LP} that allows delivery of the maximum output power is obtained when the minimum RF plate voltage and the maximum RF grid voltage are equal.) The procedure for determining the value of R_{LP} from the values of these variables is beyond the scope of this chapter and book. However, how the operating value of R_{LP} is obtained will be explained later, but it should be understood that all the available (or maximum) power delivered to the load occurs when $R_L = R_{LP}$.

Of the four independent variables listed above, the DC plate voltage is usually not readily available for adjustment—it is the voltage supplied by the power supply. On the other hand, adjustment of grid bias E_C is available to set the bias voltage that controls the resting plate current to the desired value. The grid bias adjustment determines angle θ of the plate-current conduction time, which in turn determines the value of R_S, as explained earlier. The grid drive level control adjusts the input signal grid voltage E_g, which determines the amplitude of the plate current. The final settings of these adjustments presets the value of R_{LP}, and thus determines the value of R_L, equal to R_{LP}, required to deliver all available power into the pi-network, and finally into the load.

So what is the importance of the value of R_{LP}? And its relation to R_S? First, we need to know that there is a specific amount of RF output power available during any combination of the independent variables. After grid bias E_C is set initially to the desired value it is usually left undisturbed thereafter. Because the DC plate voltage is a given, the grid drive level is the only remaining adjustment for setting the value of R_{LP}. Next, we are ready to adjust the output loading and plate tuning controls to couple the RF power into the feedline or load. With the grid drive adjusted to the level that will cause the plate current to reach the desired level, we increase the output loading to the point of maximum delivery of power, while keeping the network at resonance with the plate tuning control. At this point all of the power available for the value of R_{LC} set by that particular combination of the independent variables is being delivered. The reason is that with these settings of the loading and plate tuning controls, the load impedance at the output of the pi-network has been transformed to the resistance R_L appearing at its input terminals, equal to resistance R_{LP} appearing at the plate looking upstream from the pi-network. In other words, when resistance R_L appearing at the input of the pi-network tank circuit equals R_{LP}, all the power available under the present conditions is delivered to the load, regardless of the value of R_S.

This is a second basis for disproving the incorrect definition of the conjugate match that R_L must equal R_S for a conjugate match to exist, because the value of R_S does not appear as a condition responsible for achieving delivery of all the available power. As we know from the correct definition of the conjugate match, it exists when all the available power is being delivered to the load.

As stated earlier, the value of R_{LP} during any of these conditions is found by applying a Fourier analysis on the plate current waveform. The practical and most-used procedure for applying the Fourier analysis is the Chaffee analysis, from which the slope of the load line representing R_L is determined, as noted in Chapter 19. It is important to remember that R_L is simply the ratio of peak plate voltage E to peak plate current I, E/I, appearing at the input of the pi-network, when the all available power is being delivered to the load.

It is evident that the plate current flows through both R_S and R_L, thus the DC, fundamental AC, and all harmonic components appear across R_S. However, the high Q of the of the pi-network tank circuit at resonance provides a very low (near zero) impedance to the DC and harmonic components, but a relatively high resistance R_L to the fundamental. Thus the tank circuit impedes the DC and high-order harmonic frequencies, but passes only the fundamental frequency and low levels of low-order harmonic frequencies, which is why the output of the tank circuit is essentially a sine wave. In other words, only the fundamental and low-level harmonic frequency current flows through R_L.

We now come to a third basis for proving the new incorrect definition of the conjugate match requiring that $R_S = R_L$ invalid. In the article[142] that presented the new, invalid definition of the conjugate match, Bruene performed an experiment which he thought measured the value of R_S as the source resistance of the RF power amplifier. Fig 4 in that article displays plots of what he believes to be the relationship between R_S and R_L. Those plots show that his measurements indicate that the difference between values of R_S and R_L are constant over a large range of power levels. From the outset I have doubted the validity of those measurements reported in the article, that the value of R_S can be measured with the equipment described, or that the value of R_S can be measured at all, because R_S is a dynamic resistance occurring only as an inverse feedback to the plate current, not a resis**tor** that can be measured. In the discussion above that defines R_S as the value of R_P depending on the conduction angle θ of the plate current, it is evident that the value of R_S changes inversely with changes in angle θ. However, my own experimental data shows that R_L remains nearly constant over a wide range of power levels. Clearly, then the difference between R_S and R_L cannot remain constant over a range of power levels, as indicated in Fig 4 in the article. Consequently, the experimental data reported in the article is incorrect, and does not support the new definition of the conjugate match claimed in the article.

Sec 19A.5 Additional Experimental Data

The source resistance data reported in Secs 19.8 and 19.9 were obtained using the load variation method with resistive loads. Note that of the six measurements of output source resistance reported in Table 19.1, the average value of the resistance is 50.3 ohms obtained with the reference load resistance of 51.2 ohms, exhibiting an error of only 1.8 percent. However, various critics assert that proof of a conjugate match between the source and load requires the load to contain reactance. Accordingly, the experimental data reported below were obtained using both the load variation method and an indirect method for determining the source impedance of the RF power amplifier, with a resistive load to obtain a reference source resistance and a complex load to determine the complex source impedance that is then proven to be the conjugate of the complex load.

We'll now examine the experimental data that resulted from measurements performed subsequent to those reported in Chapter 19, new data that provides additional evidence that a conjugate match exists at the output terminals of an RF power amplifier when all of its available power is delivered into its load, however complex the load impedance. According to the definition of the conjugate match as explained earlier, if this condition prevails there is a conjugate match. In addition, the data presented below also provides further evidence that the output source resistance of the RF amplifier is non-dissipative. The following steps describe the experimental procedure I employed and the results obtained:

1. Using a Kenwood TS-830S transceiver as the RF source, the tuning and loading of the pi-network are adjusted to deliver all the available power into a 50 + j0-ohm load with the grid drive adjusted to deliver the maximum of 100 watts at 4 MHz**,** thus establishing the area of the RF power window at the input of the pi-network, resistance R_{LP} at the plate, and the slope of the load line. The output source resistance of the amplifier in this condition will later be shown to be 50 ohms. In this condition the DC plate voltage is 800 v and plate current is 260 ma. DC input power is therefore 800 v × 0.26 a = 208 w. Readings on the Bird 43 wattmeter indicate 100 watts forward and zero watts reflected. **(**100 watts is the maximum RF output power available at this drive level.) From here on the grid drive is left undisturbed, and the pi-network controls are left undisturbed until Step 10.

2. The amplifier is now powered down and the load resistance R_L is measured across the input terminals of the resonant pi-network tank circuit (from plate to ground) with an HP-4815 Vector Impedance Meter. The resistance is found to be approximately 1400 ohms. Because the amplifier was adjusted to deliver the maximum available power of 100 watts prior to the resistance measurement, resistance R_{LP} looking into the plate (upstream from the network terminals) is also approximately 1400 ohms. Accordingly, a non-reactive 1400-ohm resistor is now connected across the input terminals of the pi-network tank circuit and source resistance R_{OS} is measured looking rearward into the output terminals of the network. Resistance R_{OS} was found to be 50 ohms.

3. Three 50-ohm dummy loads (a 1500w Bird and two Heathkit Cantennas) are now connected in parallel to provide a purely resistive load of 16.67 ohms, and used to terminate a coax of 13.5° length at 4 MHz.

4. The impedance Z_{IN} appearing at the input of the 13.5° length of coax at 4 MHz terminated by the 16.67-ohm resistor of Step 3 is measured with the Vector Impedance Meter, and found to be 20 ohms at $\angle +26°$. Converting from polar to rectangular notation, $Z_{IN} = 17.98 + j8.77$ ohms. ($Z_{IN} = Z_{LOAD}$ from the earlier paragraphs.) This impedance is used in Steps 5 and 6 to provide the alternate load impedance in the load-variation method for determining the complex output impedance of the amplifier, and for proving that the conjugate match exists.

5. With respect to 50 ohms, Z_{IN} from Step 4 yields a 2.88:1 mismatch and a voltage reflection coefficient $\rho = 0.484$. Therefore, power reflection coefficient $\rho^2 = 0.235$, transmission coefficient $(1 - \rho^2) = 0.766$, and forward power increase factor $1/(1 - \rho^2) = 1//0.766 = 1.306$.

6. Leaving pi-network and drive level adjustments undisturbed, the 50-ohm load is now replaced with the coax terminated with the 16.67-ohm load from Step 4, thus changing the load impedance from 50 ohms to $17.98 + j8.77$ ohms, the input impedance Z_{IN} of the coax.

7. Due to the 2.88:1 mismatch at the load, neglecting network losses and the small change in plate current resulting from the mismatch, approximately the same mismatch appears between R_{LP} and Z_L at the input of the pi-network. Consequently, the change in load impedance changed the network input resistance R_L from 1400 ohms to complex $Z_L \approx 800 - j1000$ ohms, measured with the Vector Impedance Meter using the method described in Step 2. To verify the impedance measurement of Z_L the phase delay of the network was measured using an HP-8405 Vector Voltmeter and found to be 127°. Using this value of phase delay the input impedance Z_L was calculated using two different methods; one yielding $792 - j1003$ ohms, the other yielding $794.6 - j961.3$ ohms, thus verifying the accuracy of the measurement. However, because grid voltage E_C, grid drive E_g, and plate voltage E_B are left unchanged, resistance R_{LP} at the plate has remained at approximately 1400 ohms, leaving a mismatch between R_{LP} and Z_L at the input of the pi-network. As stated above, this value of Z_L yields the substantially the same mismatch to plate resistance R_{LP} as that between the output impedance of the pi-network and the $17.98 + j8.77$-ohm load, i.e., 2.88:1. This mismatch at

the network input results in less power delivered into the network, and thus to the load, a decrease in the area of the RF window at the network input, and a change in the slope of the loadline. (It must be remembered that the input and output mismatches contribute only to mismatch loss, which does not result in power delivered and then lost somewhere in dissipation. As we will see in Step 8, the mismatch at the input of the pi-network results only in a **reduced delivery** of source power proportional to the degree of mismatch.)

8. Readings on a Bird 43 power meter now indicate 95w forward and 20w reflected, meaning only 75 watts are now delivered by the source and absorbed in the mismatched load. The 20w reflected power remains in the coax, and adds to the 75 watts delivered by the source to establish the total forward power of 95w.

9. We now compare the measured power delivered with the calculated power, using the power transmission coefficient, $1 - \rho^2$. The calculated power delivered is: $100\text{w} \times (1 - \rho^2) = 76.6\text{w}$, compared to the 75w indicated by the Bird wattmeter. However, because the new load impedance is less than the original 50 ohms, and also reactive, the amplifier is now overloaded and the pi-network is detuned from resonance. Consequently, the plate current has increased from 260 to 290 ma, plate voltage has dropped to 760 v, and DC input power has increased from 208 w to 220.4 w.

10. With the 17.98 + j8.77-ohm load still connected, the pi-network loading and tuning are now re-adjusted to again deliver all available power with drive level setting still left undisturbed. The readjustment of the plate tuning capacitor has increased the capacitive reactance in the pi-network by –8.77 ohms, canceling the +8.77 ohms of inductive reactance in the load, returning the system to resonance. The readjustment of the loading control capacitor has decreased the output capacitive reactance, thus reducing the output resistance from 50 to 17.98 ohms. Thus the network readjustments have decreased the output impedance from 50 + j0 to 17.98 – j 8.77 ohms, **the conjugate of the load impedance,** 17.98 + j8.77 ohms. The readjustments have also returned the network input impedance Z_L to 1400 + j0 ohms (again equal to R_{LP}), have returned the original area of the RF window at the network input, and have returned the slope of the loadline to its original value. For verification of the 1400-ohm network input resistance after the readjustment, Z_L was again measured using the method described in Step 2, and found it to have returned to 1400 + j0 ohms.

11. Bird 43 power meter readings following the readjustment procedure now indicate 130w forward and 29.5w reflected, indicating 100.5w delivered to the mismatched load.

12. For comparison, the calculated power values are: Forward power = 100 × 1.306 = 130.6w, reflected power = 30.6w, and delivered power = 130.6w – 30.6w = 100w showing substantial agreement with the measured values. (1.306 is the forward power increase factor determined in Step 5.) Plate current has returned to its original value, 260 ma, and likewise, plate voltage has also returned to the original value, 800 v. Consequently, the DC input power has also returned to its original value, 208 w.

13. It is thus evident that the amplifier has returned to delivering the original power, 100 watts into the previously mismatched complex-impedance load, now conjugately matched, the same as when it was delivering 100 watts into the 50-ohm non-reactive load. But **the reflected power, 30.6 watts, remains in the coax**, adding to the 100 watts delivered by the amplifier to establish the 130.6 watts of forward power, proving that it does not enter the amplifier to dissipate and heat the network or the tube.

It must be kept in mind that impedance Z_{IN} appearing at the input of the 13° line connecting the 16.7-ohm termination to the output of the amplifier is the result of reflected waves of both voltage and current, and thus reflected power is returning to the input of the line, and becomes incident on the output of the amplifier.

The significance of these measurement data is that for the amplifier to deliver all of its available power (100w) into the mismatched load impedance $Z_{IN} = 17.98 + j8.77$ ohms, the readjustment of the tuning and loading of the pi-network simply changed the output impedance of the network from 50 + j0 ohms to 17.98 – j8.77 ohms, **the conjugate of the load impedance**, thus matching the output impedance of the network to the input impedance of the coax. Consequently, there IS a conjugate match between the output of the transceiver and its complex load. QED. The readjustments of the pi-network simply changed its impedance transformation ratio from 50:1400 to (17.98 – j8.77):1400, returning the input resistance R_L of the pi-network to 1400 ohms, the value of R_{LP}. Thus the plates of the amplifier tubes are unaware of the change in external load impedance.

14. We'll now make an additional indirect measurement of R_{OS} that proves the conjugate match statement above is true. Leaving the pi-network adjustments undisturbed from the conditions in Step 10, with the amplifier powered down we again connect a 1400-ohm non-reactive resistor across the input terminals of the pi-network tank circuit and measure impedance Z_{OS} looking rearward into the output terminals of the network. The impedance was found to be $Z_{OS} = 18 - j8$ ohms.

From a practical viewpoint, measured impedance $Z_{OS} = 18 - j8$ ohms is the conjugate of load impedance $Z_{LOAD} = 17.98 + j8.77$, proving that the amplifier is conjugately matched to the load, and also proving the validity of the indirect method in determining that the source impedance of the amplifier is the conjugate of the load impedance when all available power is being delivered to the load.

Thus the data obtained in performing Steps 1 through 14 above proves the following four conditions to be true:

No reflected power incident on the output of the amplifier is absorbed or dissipated in the amplifier, because:

1. The total DC input power is the same whether the amplifier is loaded to match the resistive Z_0 load of 50 + j0 ohms, with no reflected power, or to match the complex load of 17.98 – j8.77

ohms with 30.6 watts of reflected power, while 100 w is delivered to either the Z_0 load or the re-matched complex load.

2. All the 100 watts of power delivered by the transmitter is absorbed in both the Z_0 load and the re-matched complex load cases, with the same DC input power in both cases.

3. All the 30 watts of reflected power has been shown to add to the source power, establishing the total 130 watts of forward power in the case involving the re-matched complex load.

4. All the reflected power is added to the source power by re-reflection from the non-dissipative output source resistance R_{OS} of the amplifier. Had the output source resistance of the amplifier been dissipative the reflected power would have been dissipated there to heat, instead of being re-reflected back into the line and adding to the source power. In addition, the Bird 43 power meter would have indicated 75 watts of forward power, not 95. This proves that reflected power incident on the output of the amplifier does not cause heating of the tube.

It should also be noted, an accepted alternative to the load-variation method for measuring the output impedance of a source of RF power is the indirect method demonstrated above. As performed during the measurements described above, the procedure for this method is to first make the necessary loading adjustments of the output network to ensure that all of the available power is being delivered to the load. Next, the input impedance of the load is measured. It then follows that, as proven above, the source impedance is the conjugate of the input impedance measured at the input of the load, because when all available power is being delivered to the load, this condition conforms to the Conjugate Matching and the Maximum Power-transfer Theorems[17].

Additionally, I previously performed this same measurement procedure using a HeathKit HW-100 transceiver, using several different lengths of coax between the 16.7-ohm load and the output of the transceiver in each of several measurements. The different lengths of coax provided different complex load impedances for the transceiver during each measurement. The same performance as described above resulted with each different load impedance, providing further evidence that a conjugate match exists when the amplifier is delivering all of its available power into its load. These results also prove that the single test with the Kenwood transceiver is not simply a coincidence.

Sec 19A.6 Summary

More recent experimental evidence has been presented since that of Chapter 19, adding further proof that a conjugate match can exist when the source is an RF power amplifier, and that the output source resistance of the amplifier is non-dissipative. It was also shown that R_{LP} looking toward the plate from the network input equals resistance R_L appearing at the input of the pi-network when a conjugate match is obtained, while contrary to Bruene's claim, there is no requirement that $R_L = R_S$ to obtain a conjugate match, thus proving Bruene's definition of the conjugate match appearing in his November 1991 *QST* article [142] invalid.