TP-162
Application Guide

Optimizing Double-Tuned Output Circuits For Tetrode Power Amplifiers

Using the BURLE Y1400/9017 1kW UHF Cavity Amplifier as the Demo Circuit

BURLE- TV Broadcast- Power Tubes, Circuits & Applications

BURLE Industries, Inc. has a long history of designing & manufacturing power tubes & amplifiers for the TV Broadcast Industry.

BURLE Power Tube Engineering previously designed a complete line of linear TV broadcast tubes & cavity circuits for both visual & combined services. They covered both the Low & High VHF bands at power levels from 500 to 50 kW sync. Many transmitter OEM’s, such as Acrodyne, Emcee, Harris, ITS, Larcan, NEC & RCA designed these RCA/BURLE products into their "Second Generation" transmitters. These transmitters are still in wide use today.

At this juncture, BURLE Industries, Inc. continues to provide extensive full time Applications Assistance to their many customers in TV Broadcast who still use BURLE products. How ever, during The past 5 to 10 years, it has become increasingly evident that there is a dire need for a tutorial document that should be both useful & instructive for teaching the fundamentals of double-tuned output circuit theory. This Application Guide, TP-162, is intended to satisfy that need.

For this tutorial, the BURLE Y1400/9017 1kW UHF cavity amplifier circuit was chosen as the demonstration vehicle be cause its’ output circuit configuration typifies virtually all of the tetrode power amplifiers in high band VHF & all of UHF. That is, it contains the standard shorted distributed transmission line sections for both PRIMARY & SECONDARY TUNING & series lumped capacity is utilized for both COUPLING & LOADING. Also, there is a plethora of Design & Measured data that already exists on the Y1400/9017 cavity amplifier which makes this task much easier. The following is a brief background history of the Y1400/9017 cavity amplifier.

BURLE Y1400/9017 Cavity Amplifier-

The design of the BURLE Y1400/9017 cavity amplifier began in February, 1982. The initial development was completed in early 1985. The first production tubes were shipped in June, 1985. Ongoing improvements were made through April, 1986. The major features of the Y1400 cavity are; (1) snap-in solder-less r.f. finger contacts located in the tube socket, (2) solder-less "sticky" r.f. contact fingers located in all sliding tuning shorts & (3) ease of maintenance & repair using only simple tools.

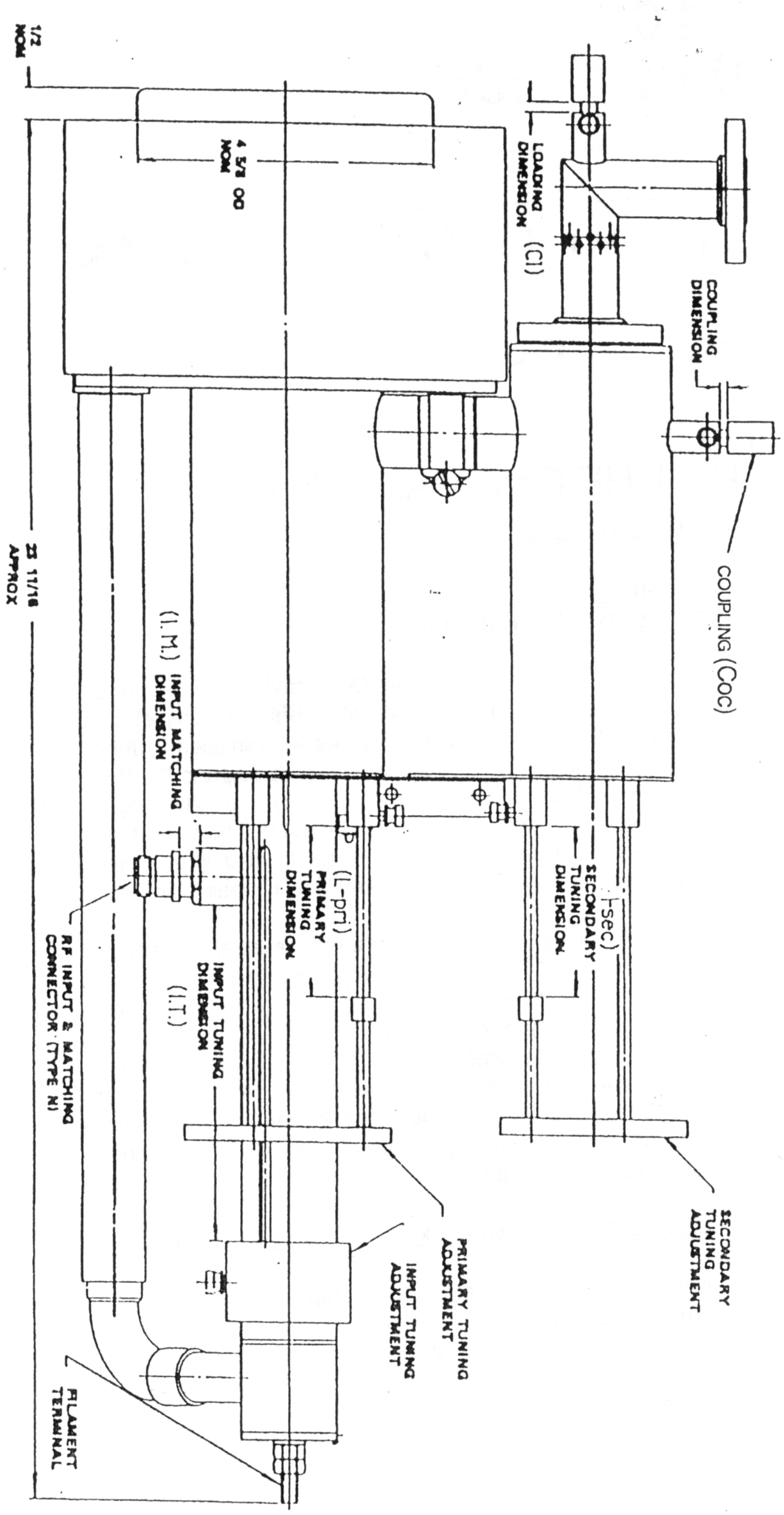
This major design effort produced a very reliable, high performance Y1400/9017 UHF cavity amplifier circuit. Its’ overall performance matched that of the 1kW UHF competition & it did so at considerably lower cost to the end user.

In summary, as testament to BURLE’s excellent Y1400/9017 performance, all three major domestic UHF 1kW transmitter OEM’s opted to use the Y1400/9017 in their new transmitter designs. There are now over 600 of these units in field use today, far more than any other BURLE design.

Double-Tuned Output Ckt. -Methods of Analysis-

A set of computer generated tutorial graphs is shown in **Section I** which demonstrate how each of the (4) output circuit adjustments changes the shape of the swept response as compared to a standard REFERENCE curve. The behavior of these (4) output circuit adjustments should be studied & memorized. Two computer model examples are given in **Section II** to determine if the reader can follow a logical "step-by-step” procedure without any hesitation or "second guessing”. **Section III** demonstrates how favorable the measured 250 watt empirical data compares with the computer model data.

-Double-Tuned Output- -Location of the Four (4) Output Circuit Adjustments-



-PRIMARY TUNING (L-pri)-
&
-SECONDARY TUNING (L-sec)-

Both PRIMARY & SECONDARY TUNING adjustments consist of a (3) rod push ring arrangement which is used to change the resonant frequency of each circuit by changing the mechanical position of an R.F. fingered tuning short. Three (3) locking screws are used on each circuit. See Figure 2 for more detail.

-COUPLING (Coc)-

This is a single push rod adjustment used to vary the coupling between the PRIMARY & SECONDARY circuits by varying the value of a series capacitor. It is located on the SECONDARY circuit positioned at a right angle to the main axis. A locking screw is provided. See Figure 2 for more detail.

-LOADING (Cl)-

This is a single push rod adjustment which is used to vary the value of a series capacitor to the 50 ohm external load. This adjustment is located on the 7/8" right angle output adapter. A locking screw is provided. See Figure 2 for more detail.

Figure 1- BURLE Y1400/9017 1.1 kW Cavity Amplifier Outline

-FEATURING-

- Typical Gain >15dB
- Typical -54dB IMD_3
- Ease of Maintenance
- Only Simple Tools Required
- Captive Solder-less R.F. Finger Contacts Utilized In Tube Socket & Sliding Tuning Shorts

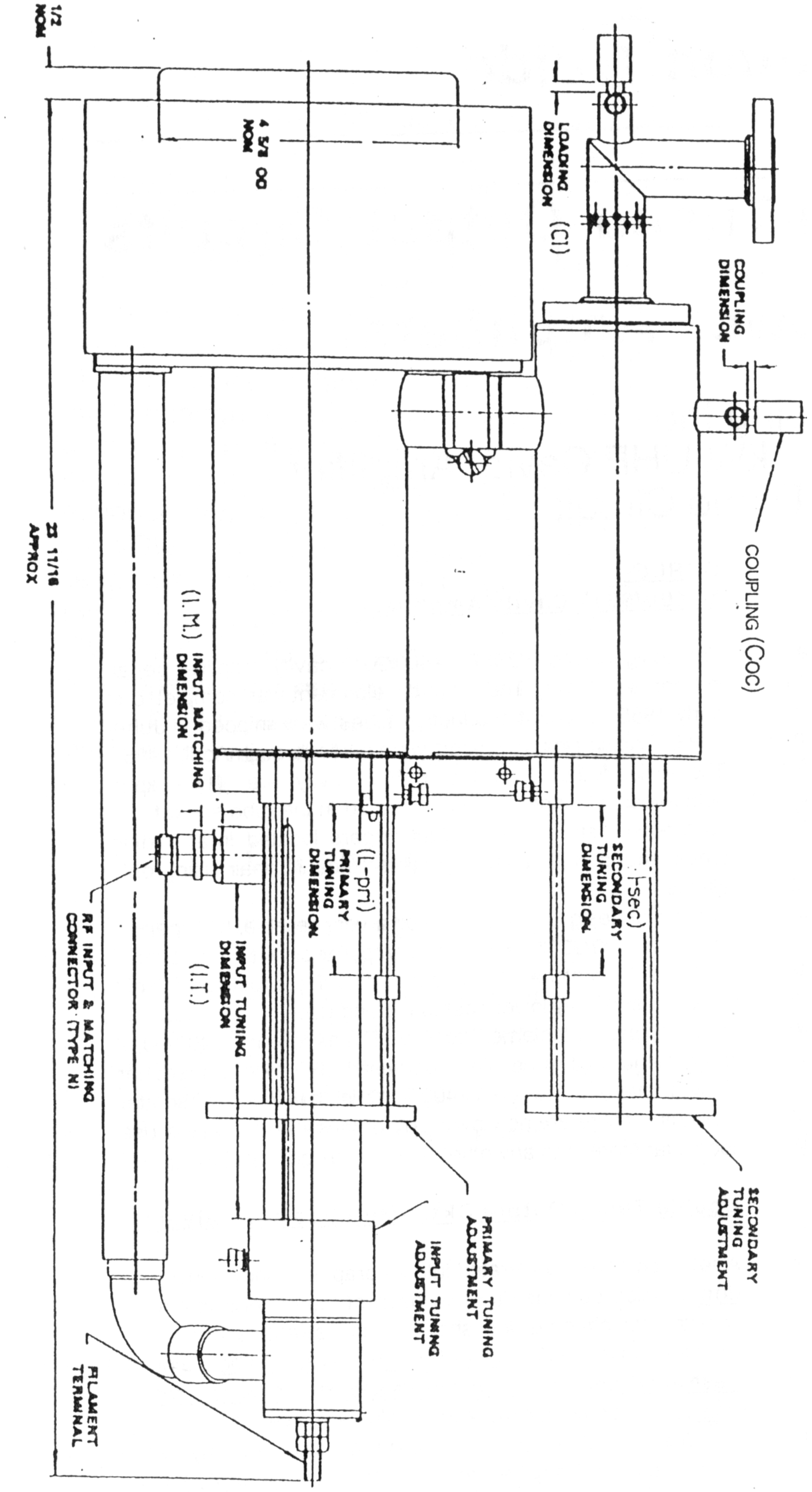
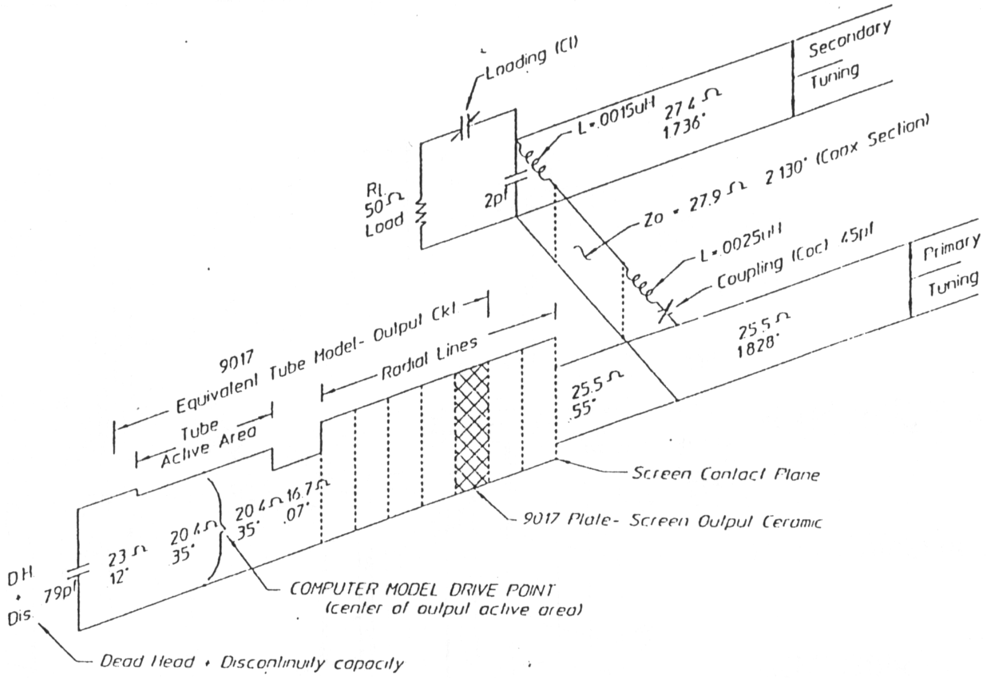


Figure 2- BURLE Y1400/9017 1.1 kW Cavity Amplifier Cross-Section



-**Figure 3**-

-BURLE Y1400/9017 1.1 kW UHF Cavity Amplifier-
-Two (2) Wire Equivalent Output Circuit Model-

The output circuit model shown in Figure 3 above is the same two (2) wire equivalent circuit that was successfully used to develop the Y1400 cavity amplifier beginning in February, 1982. It was used to optimize the response shape of the "R" component of the impedance transfer function of the double-tuned output circuit all across the UHF frequency band.

The drive point impedance method was used to analyze the network starting with the 50 ohm load, then back through the secondary, the over-coupling arm, the primary & then on through to the center of the active area of the tube. This drive point impedance method is well known to furnish useful information for the design of output networks. The center of this active area, between plate & screen, can be visualized as the point where the total tetrode current is injected into an equivalent series impedance that is presented by the complex output circuit. The output power response will then match the frequency response of the "R" component of the impedance vs frequency; i.e., power = current squared x R. (NOTE- of the response curves shown in this Application Guide are plots of the resistive component of the complex output Impedance presented current beam at the center of the active area of the output circuit & therefore correspond output power response for a constant current tetrode tube).

Early tube samples were "cold probed" to ensure that the computer model closely matched the empirical measured data.

The design approach consisted of a series of circuit changes which finally led to an output configuration that produced a load resistance value that gave over 15 dB gain at 8 Mhz instantaneous BW. Gain was optimized in the center of the UHF band. Low end gain was compromised to match the upper end gain. Transit time effects were minimized during initial testing. Spurious was eliminated with tube & circuit mods. The final design was clean & spurious free with more than 15dB typical gain & over -54dB of in band IMD3.

-Method of Analysis

-Section I -
-Output Circuit Computer Model-

The Y1400/9017 output circuit computer model was used as the basis for demonstrating, in theory, how each of the four (4) output circuit adjustments specifically changes the shape of the output response by graphically showing what happens when each of the adjustments is made either Longer or Shorter or Larger or Smaller as compared to a Reference value. See **Figures 4, 5, 6 & 7**. These four (4) computer generated graphics are intended for use as **tutorials**. Each of the output circuit adjustments behaves & responds in a very specific manner. Some of the results are very intuitive while others must be given more thought as to why the adjustment changes the response in the manner it does. There is no second guessing on what each adjustment does; e.g., you can't interchange the primary & secondary circuit resonant frequencies & expect to obtain the same response. This circuit is well defined as a series ladder diagram from load to generator; **therefore, there will only be one set of tuning adjustment rules.**

In summary, there is a specific set of tuning adjustment rules for this circuit which is relatively easy to learn & which should be committed to memory as quickly as possible. This alignment process for double-tuned output circuits will quickly become "second nature" with continued use. **This is the main thrust of this Application Note: i.e., (1) to show that there is a very specific set of tuning rules for this output circuit configuration & (2) they can be quickly learned & mastered.**

-Section II
-Computer Model Examples-

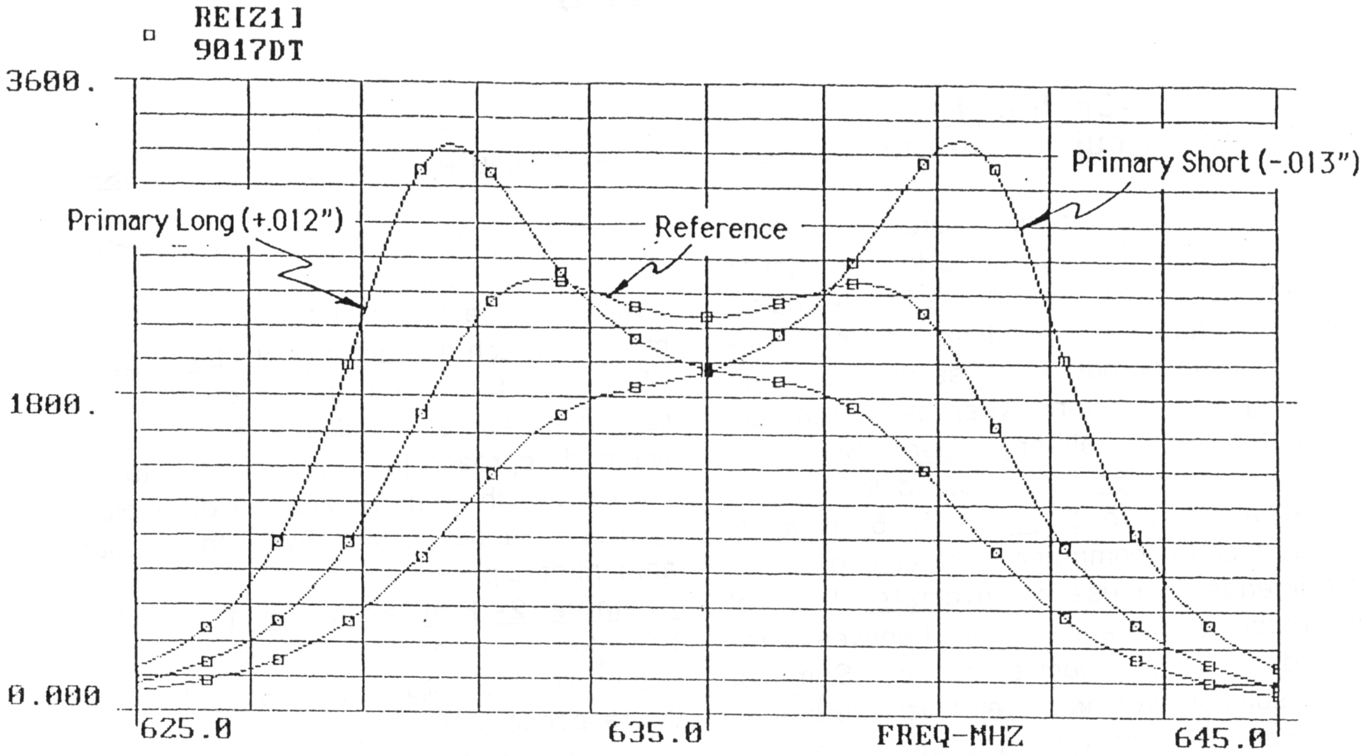
Two (2) computer model examples are shown that will provide additional understanding on how to make a series of output circuit adjustments to reach a specific goal. **Example 1 - Figures 8 to 10** provide a sequential set of response curves which demonstrate a planned approach for reducing the output circuit bandwidth from 7.9 Mhz, .41 dB ripple response to about 7 Mhz BW with the same amount of ripple.

Example 2 - Figures 11 to 13 provide a basis for understanding reactive overswing & output circuit Figure-of-Merit as a function of the response ripple. Both need to be fully understood in order to optimize the gain & pre vent screen over dissipation.

-Section III-
-CH 41- Measured 250 Watt Data-

A BURLE Y1400 cavity circuit & 9017 tube were set up in the Lab. The tube/circuit was tuned & aligned for 250 watts of CW swept power (no sync was present) at CH 41 at a Reference 8 Mhz, .4 dB BW response. **Figures 14 & 15** show all of the operational specifics. Each of the (4) output tuning adjustments were optimized for direct comparison to the previous computer model data. In general, the measured data, **Figures 16 to 19** compare very favorably with the computer data in most all respects; however, one minor exception relating to transit time delay is noted. This experiment was done using a purely resistive 50 ohm load. A cautionary note is sounded on load VSWR, particularly in conjunction with use in long lines.

Section - I -Y1400 Output Cavity Circuit Adjustments-Computer Model-

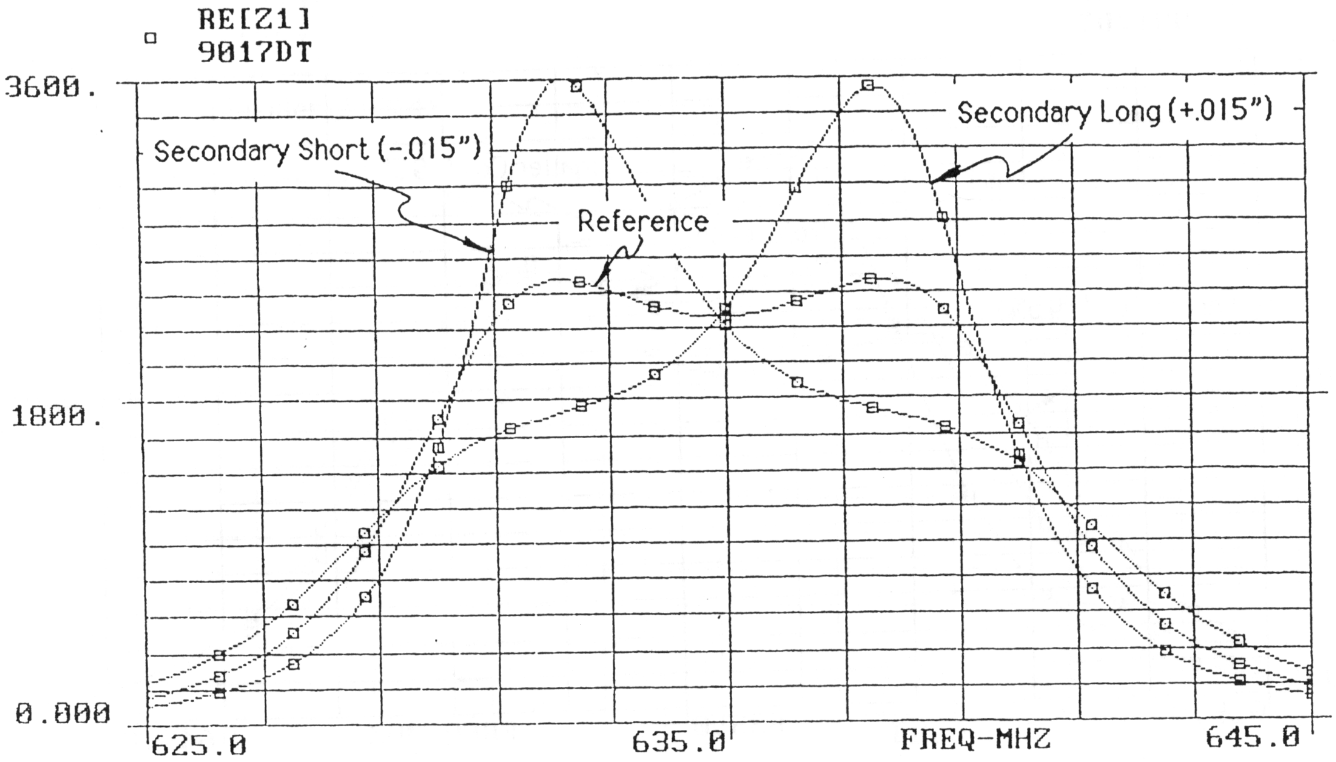


-Figure 4-
Y1400 Output Response Variation vs Primary Tuning (L-pri)

1. The **PRIMARY TUNING** adjustment fixes the frequency position of the upper mode on the double tuned response.

2. With a **LONGER PRIMARY**, the upper mode slides to a lower frequency and becomes amplitude de-emphasized (or lower mode emphasized).

3. With a **SHORTER PRIMARY**, the upper mode slides to a higher frequency and becomes amplitude emphasized.

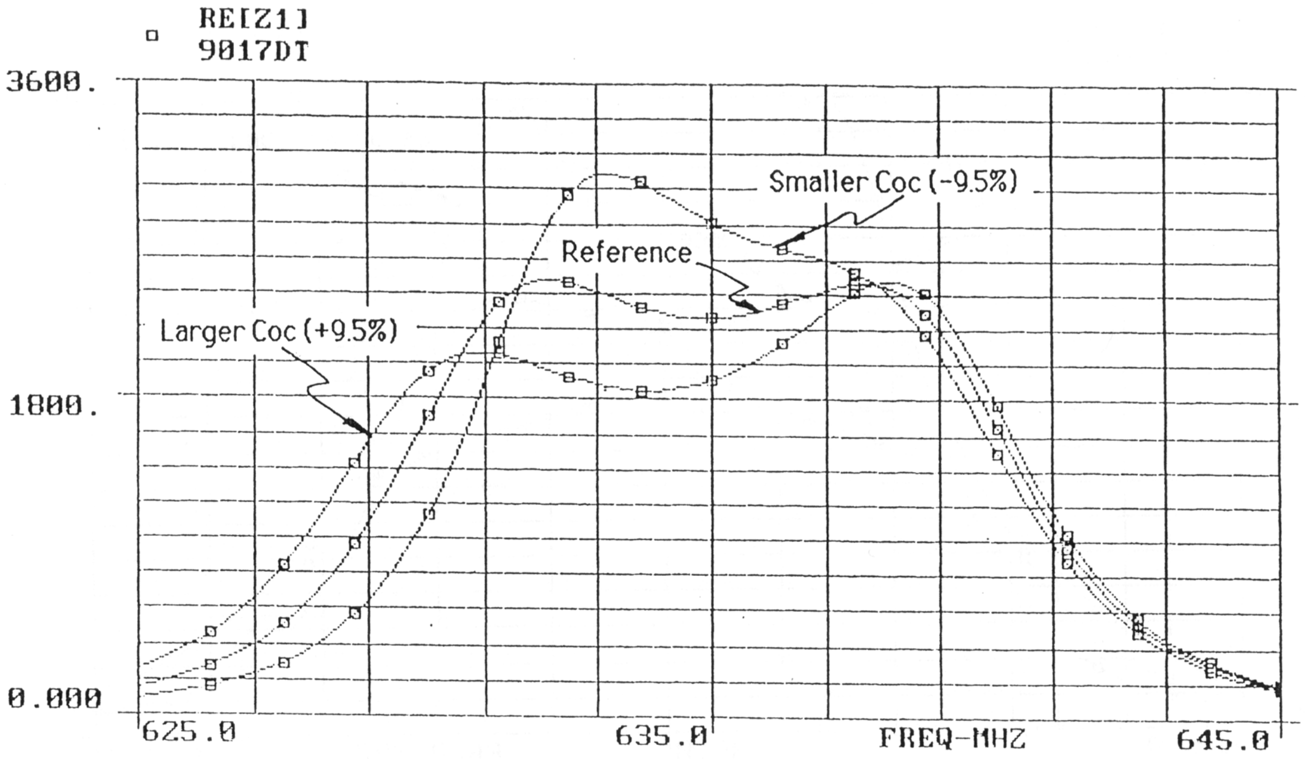


-Figure 5-
Y1400 Output Response Variation vs Secondary Tuning (L-sec)

1. The **SECONDARY TUNING** adjustment only **TILTS** the output response. There is no frequency translation.

2. With a **LONGER SECONDARY,** the upper mode becomes emphasized.

3. With a **SHORTER SECONDARY,** the lower mode becomes emphasized.

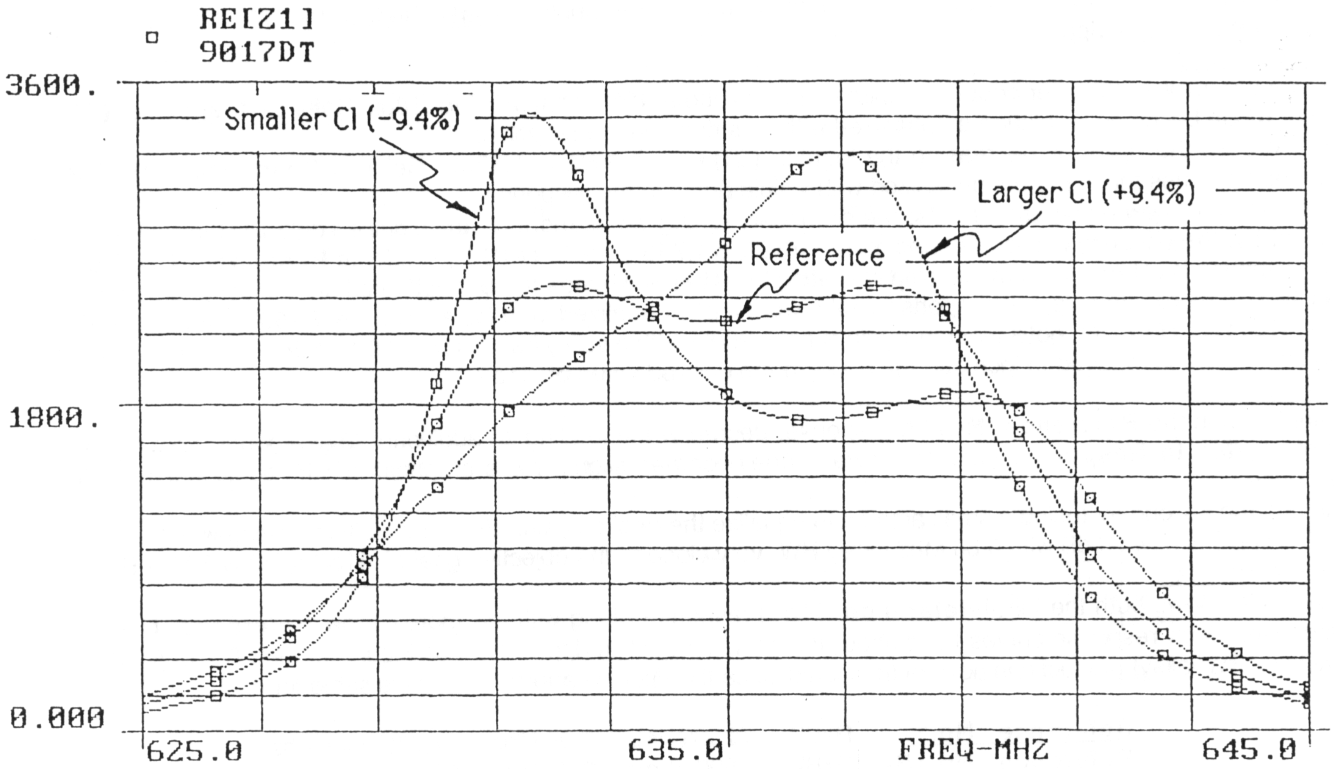


-Figure 6-
-Y1400 Output Response Variation vs Coupling (Coc)-

1 .The **COUPLING** adjustment is used to change the bandwidth of the response.

2 .**LARGER (Coc)** produces increased bandwidth with more ripple. The lower mode moves to a lower frequency with less amplitude. However, both the **SECONDARY TUNING & LOADING** adjustments must be alternately adjusted to bring the response back to **equal peaks with the same amount of ripple** as the initial **REFERENCE** response. The response bandwidth will then be **wider.**

3. **SMALLER (Coc)** produces decreased bandwidth with less ripple. The lower mode moves to a higher frequency with more amplitude. However, both the **SECONDARY TUNING & LOADING** adjustments must be alternately adjusted to bring the response back to **equal peaks with the same amount of ripple** as the initial **REFERENCE** response. The response bandwidth will then be **narrower.**



-Figure 7-
Y1400 Output Response Variation vs Loading (Cl)

1. The **LOADING** adjustment is used to change the magnitude of ripple in the output response variation.

2. **LARGER (Cl)** tilts the response causing the lower mode to become de emphasized (upper mode emphasized) along with **less** ripple. The **LARGER** value of **(Cl)** detunes the **SECONDARY** to a lower frequency. Therefore, the **SECONDARY** must be shortened to equalize the peaks. The net result will be (a) less ripple, (b) a higher value of “valley” resistance, **RE[Z1]** and (c) less valley bandwidth.

3. **SMALLER (Cl)** tilts the response causing the lower mode to become emphasized (upper mode de-emphasized) along with **more** ripple. The **SMALLER** value of **(Cl)** detunes the **SECONDARY** to a **higher** frequency. Therefore, the **SECONDARY** must be lengthened to equalize the peaks. The net result will be (a) more ripple, (b) a lower value of “valley” resistance, **RE[Z1]** and (C) more valley bandwidth.

Section - II -Example 1. - Bandwidth Reduction-Computer Model-

Given- The 7.9 Mhz BW **Reference No.1** response with .41dB rIpple. **Goal-** Reduce the BW to about 7 Mhz with the same amount of ripple.

Refer to **Figure 8-**

1. Reduce the value of the over-coupling capacitor **(Coc)** about 10%, from .21 pf to .18 pf Refer to **Response (1)**. The lower mode becomes amplitude emphasized with less ripple in the response.

2. Now increase the ripple by decreasing the loading **(Cl)** from 1.49pf to 1.39pf. Refer to **Response (2).** The tower mode becomes much more emphasized with visible ripple in the response.

3. The peaks must now be equalized. Use the secondary tuning adjustment **(L-sec)** since it only tilts the response. On the first try, the **(L-sec)** was lengthened from 1.7362 to 1.746", about (+.010"). Refer to **Response (3).** Note that the response is still low end emphasized indicating that **(L-sec**) needs to be lengthened an additional amount.

4. After two (2) more attempts, the response peaks were finally equalized with **(L-sec)** set at 1.750". Refer to **Reference No.1A**. However**,** note that the ripple Is only .26dB with a valley bandwidth of 6.11 Mhz. Therefore, more loading adjustment is required **to** Increase the ripple to the desired value of .41dB.

Refer to **Figure 9-**

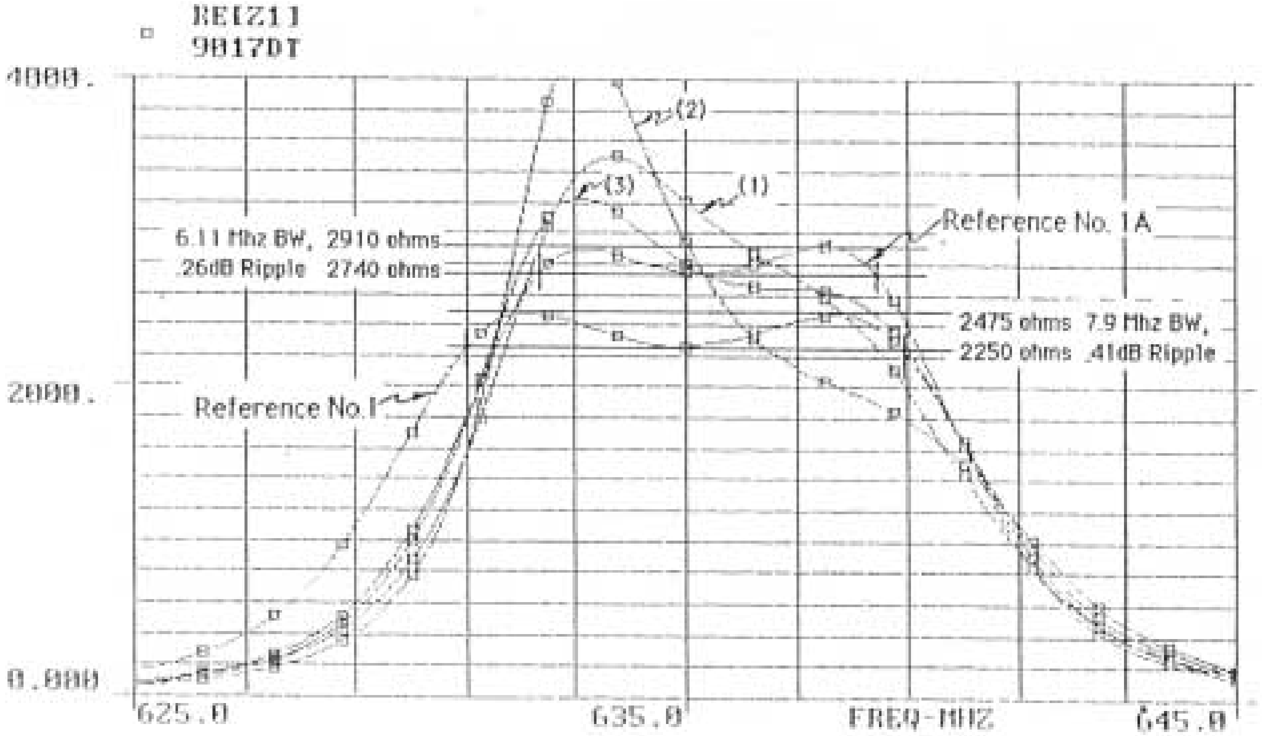
1. Beginning with the **Reference No.1 A** response, decrease the loading an additional small amount, from 1 .39pf to 1.35pf. **Refer to Response (2).** The lower mode becomes slightly more emphasized with additional ripple in the response.

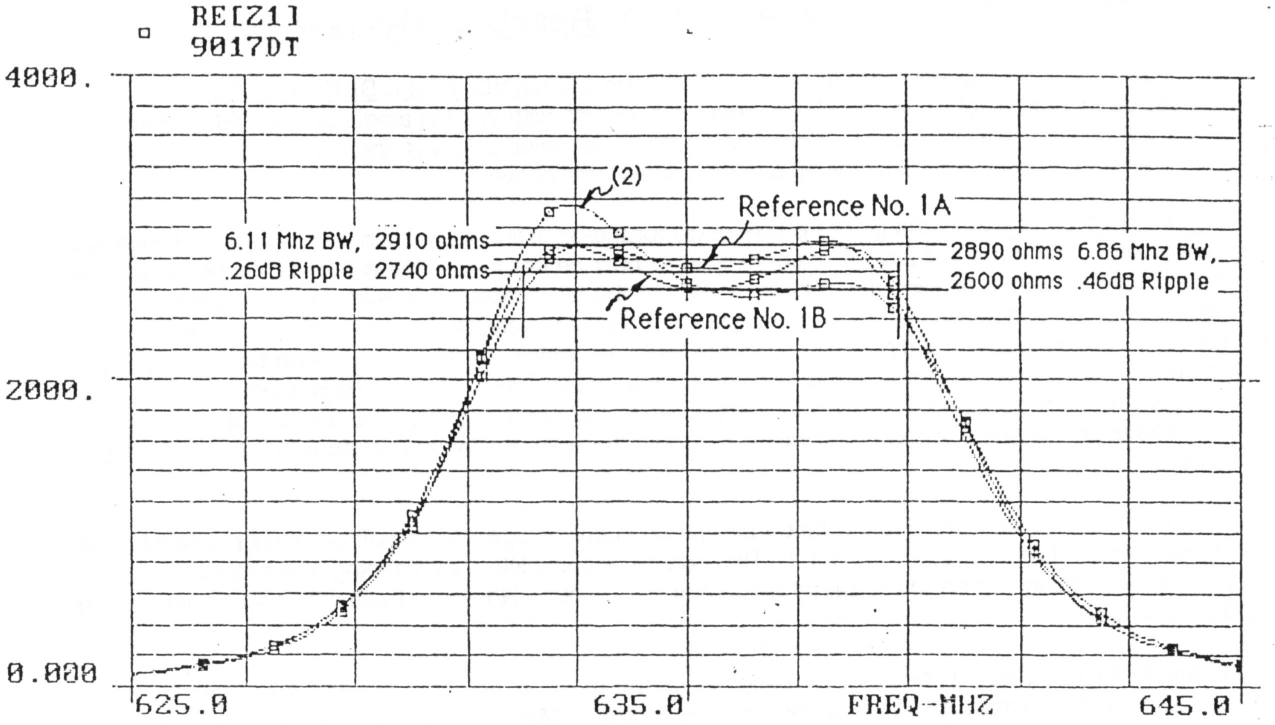
2. Lengthen the secondary tuning a small amount to equalize the peaks again. Equal peaks final setting was **(L sec)** = 1.753". Ripple is now .46dB with 6.86 Mhz valley BW, very close to the objective gal of .41dB ripple & **7** Mhz BW.

Refer to **Figure 10-**

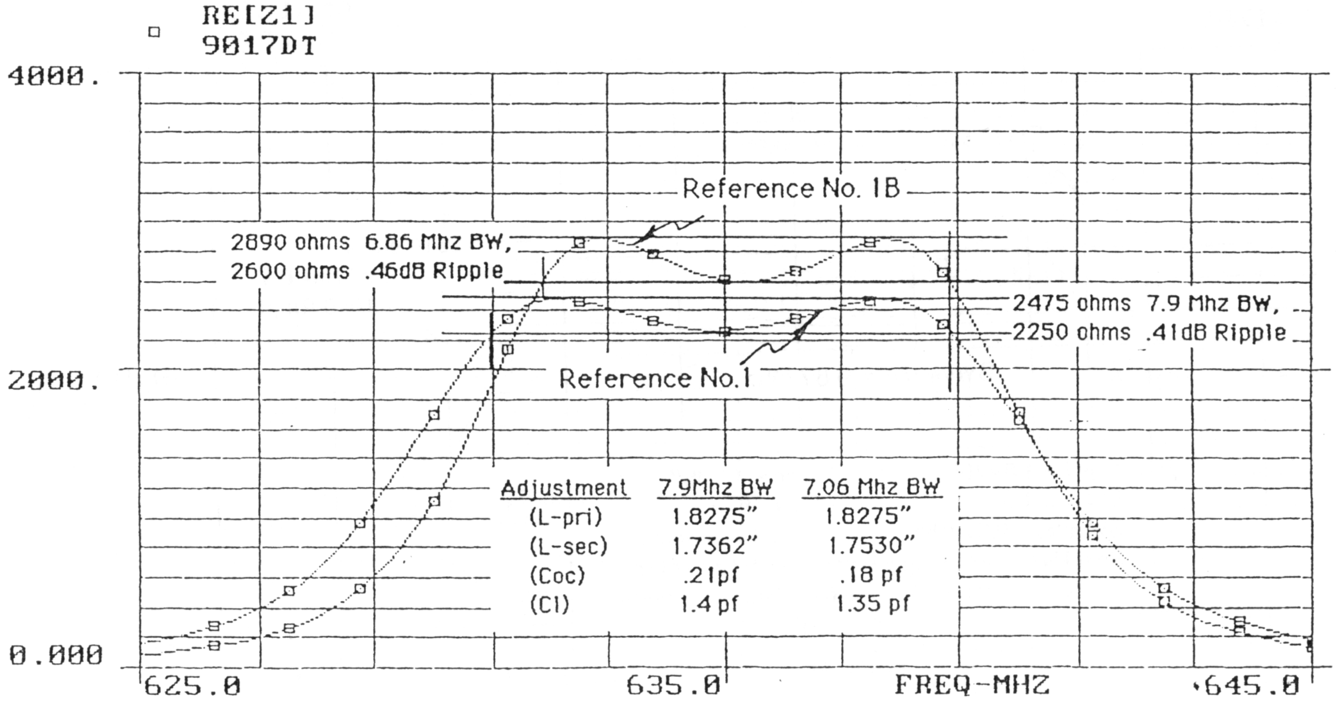
1. **Figure 10** shows both the initial **Reference No.1** response along with the more narrow **Reference No.1 B** final response. Both response curves have about the same amount of ripple. Output Figure-of-Merit (V), defined as the (Rvalley x BW valley) product can now be measured since the ripple is approximately the same for each.

Reference No.1- RxBW = 2250 ohms x 7.90 Mhz = 17,775 ohm-Mhz.
Reference No.1 B- RxBW = 2600 ohms x 6.86 Mhz = 17,836 ohm-Mhz.





-Figure 9-



Adjustment	7.9Mhz BW	7.06 Mhz BW
(L-pri)	1.8275"	1.8275"
(L-sec)	1.7362"	1.7530"
(Coc)	.21pf	.18 pf
(Cl)	1.4 pf	1.35 pf

- Figure 10 -

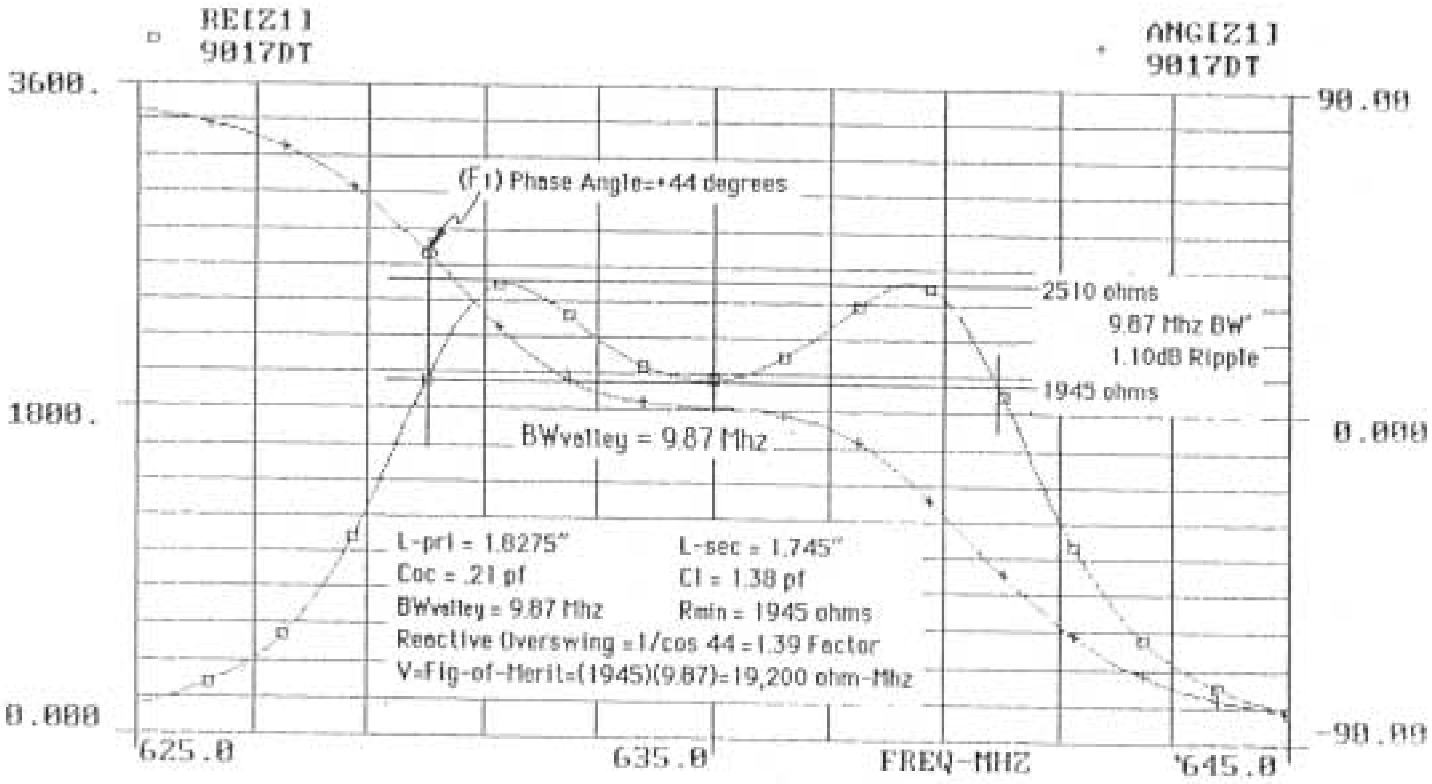
-Example 2- Figure-of-Merit (V) & Reactive Overswing

Figures 11 to 13 show that for a given value of over-coupling, the **LOADING (CL) & SECONDARY (Lsec)** adjustments can be set up to yield a set of equal peaked response curves with varying amounts of ripple & Figure-of-Merit. Figure-of-Merit is defined as the (Rvalley x BWvalley) product. Its' value peaks at about 1dB ripple then rapidly decreases below 1/2 db with an extremely slow fall oft rate with ripple level above 1dB.

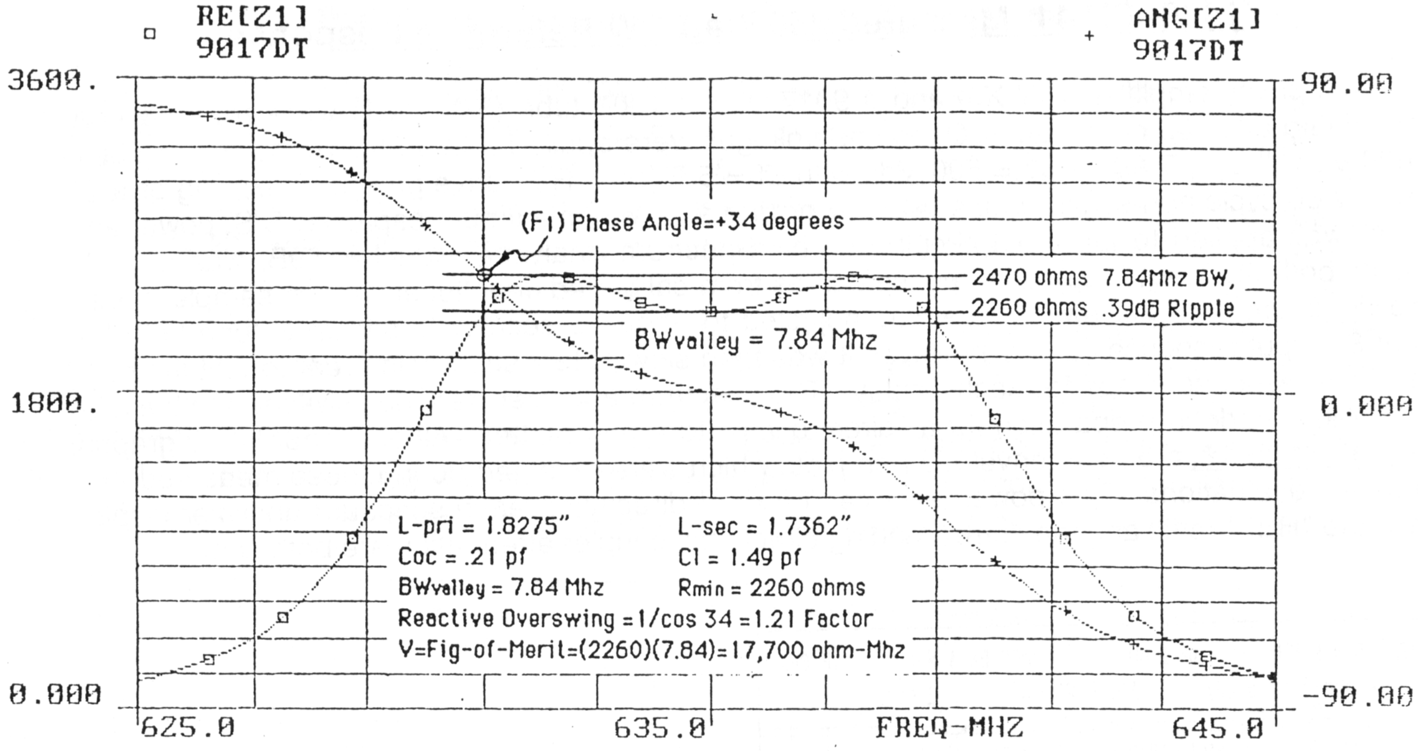
Note also that **Figures 11 to 13** show the plot of phase angle for the complex impedance vs frequency. These are standard plots which show that the imaginary component Is zero near center frequency & that it gets progressively larger at frequencies above & below the resonant mid-point Within the pass band, it's largest at the band edge. Also, the magnitude of this reactive component at the band edges gets progressively larger as a function of ripple. Therefore, the Injected tetrode beam current can produce complex voltages which are much larger than the resistive volt age produced at center frequency. This reactive overswing Is defined as Z/R = 1/cos and is a factor greater than unity. Reactive overswing considerations are especially Important in CW applications where the useful power at the band edge is the same as at mid-point. Appropriate measures must therefore be taken to ensure that the screen grid is not over dissipated.

Reactive overswing increases directly with ripple & for double tuned circuit design it's considered good practice to limit the reactive overswing factor to no greater than 1.1:1 This can be accomplished by keeping the output ripple between .4 & 1.0dB and over designing on the required amount of bandwidth. However, there will be a corresponding loss in plate efficiency & gain.

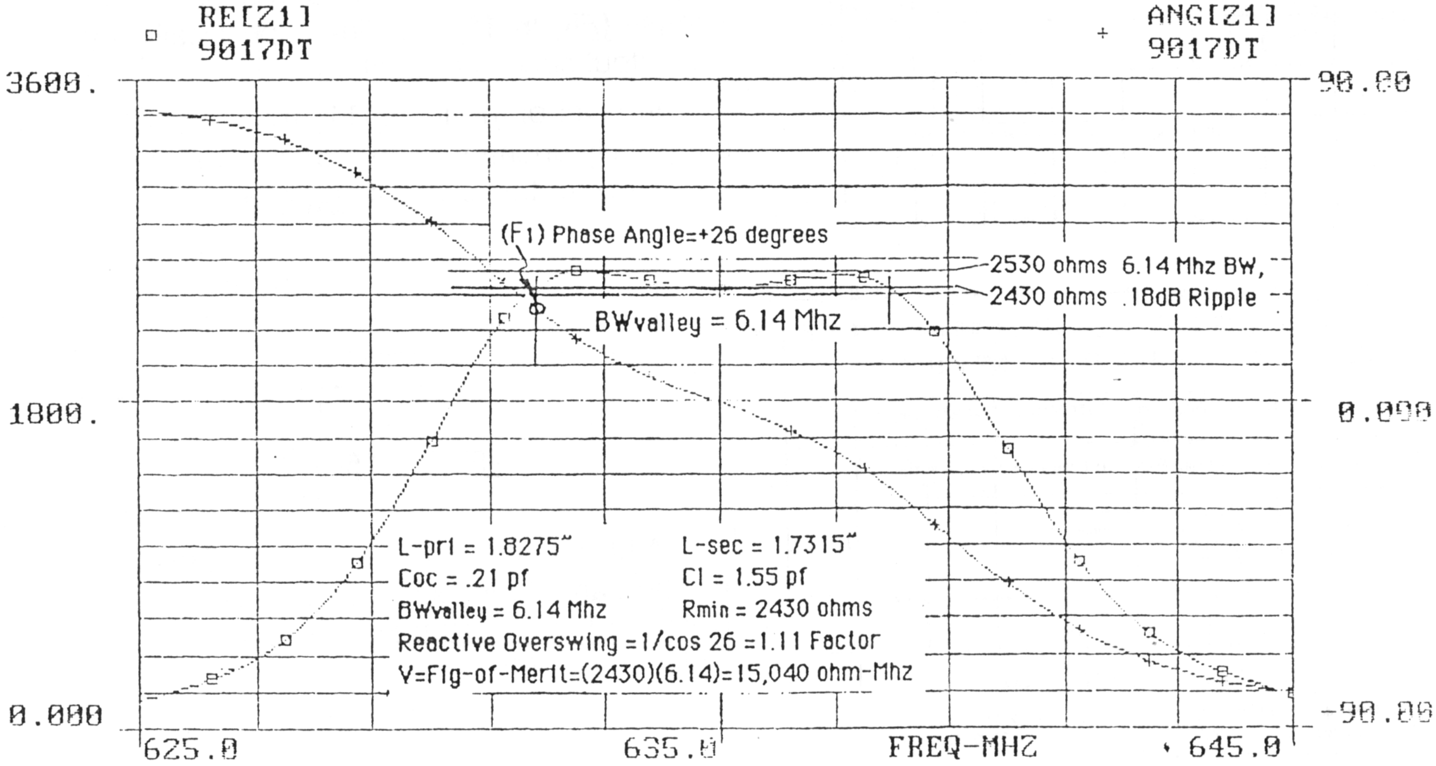
In summary, the double tuned type C (Chebyshev) response shape must be adjusted to keep the ripple level between .4 to 1.0dB in order to maintain the best compromise on Figure-of-Merit & keep the reactive overswing minimized.



- Figure 11 -



-**Figure 12**-

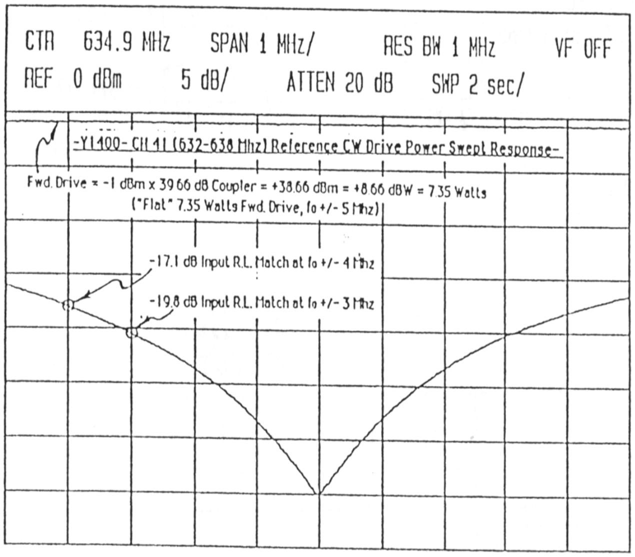


-**Figure 13**-

Section - III

-Y1400- CH 41- Measured 250 Watt CW Reference Response-

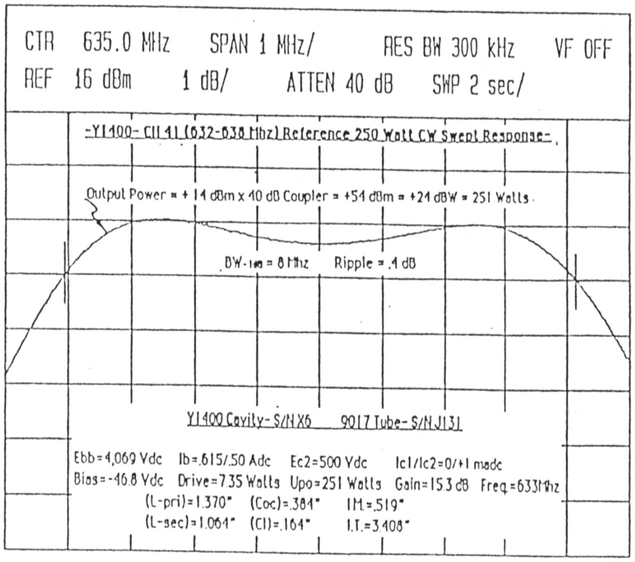
A Y1400 cavity amplifier (S/N X6) and a 9017 UHF 1.1 kW tube (S/N J131) were set up & connected into a flat 50 ohm load. Operating voltages were applied with a static condition of Ebb = 4,000 Vdc, Ibo = .5 Adc, Ec2 = 500 Vdc with Ef = 5.5Vdc. R.F. drive power, consisting of a 10 mw CW 60 cycle non-synchronous sweeper driving a 20 watt maximum capability S.S. power amplifier, was applied to the input circuit. An hP Spectrum Analyzer, Model 8569B, was used to display both the input & output response curves from calibrated directional coupler sample points. The spectrum analyzer sweep rate was adjusted to about .5 sec/Div to set up & tune both the input & output response curves; however, it was then slowed to 2 sec/Div in order to plot the peak envelope response shape for each display. The spectrum analyzer was then switched to the digital storage mode in preparation for a “direct dump” to a pen plotter. All of the following graphs, **Figures 14 to 19,** are peak envelope pen plots which were obtained during these measured performance evaluations. The power level can be read directly on each spectrum analyzer display since the “REF” level and the corresponding directional coupler attenuation are both shown.



-Figure 14-

* The input sweep is much wider than the output response. Therefore, the output response **(Figure 15)** is defined specifically by the output circuit parameters.

* The level of the input R.L. match remains essentially unchanged to a drive level as low as 10 mw for this class of operation.

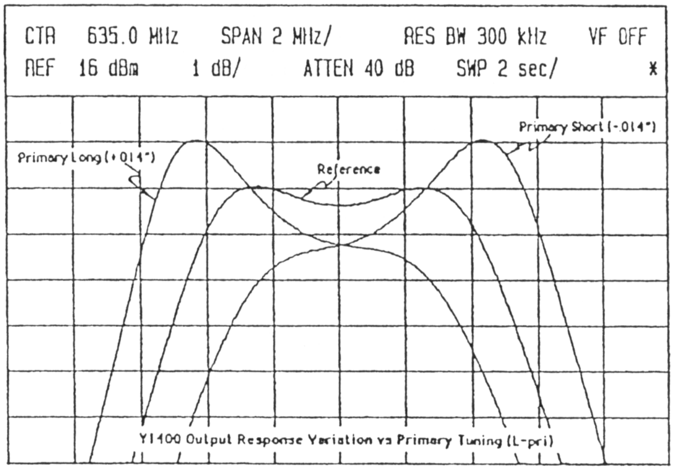


-Figure 15-

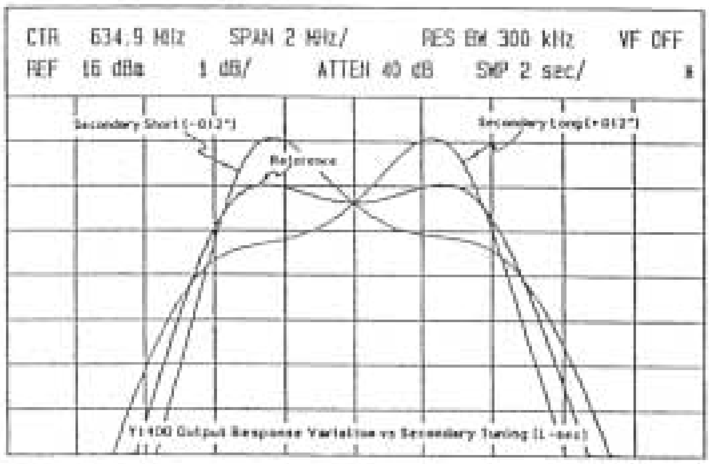
* Y1400 250 Watt CW Reference Response. The same identical Reference Response is used in **Figures 16 through 19** except it is displayed at 2 Mhz/Div..

-Y1400- CH 41- Measured 250 Watt CW Performance Data-
-Output Response Variation vs Circuit Tuning Adjustments-

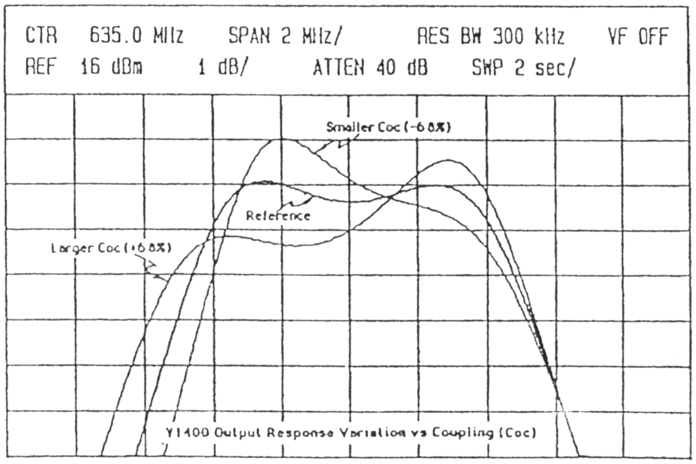
This set of CH 41 measured 250 watt CW Output Response Variation Data, **Figures 16. 1 7, 18 & 1 9,** was taken for the express purpose of comparing it respectively with the Output Response. Variations (Tutorial Data) of **Figures 5. 6. 7 & 8**, that was generated using the Y1400/9017 output circuit computer model. **In general, the measured data compares very favorably with the computer data.** However, one notable difference is that the measured data shows about 1/2 dB less tilting effects as compared to the computer data which is due primarily to transit time delay as a function of plate voltage. This was experimentally verified by dropping the drive power from 7.35 watts to 10 mw (-28.7 dB). The output power fell proportionally to .4 watts & the gain increased to about 16 dB. However, ebmin (the instantaneous plate voltage at the peak of negative swing) increased to a value approximately equal to the plate voltage thus reducing the transit time considerably. At this condition, the **RIPPLE** increased from .4 to 1.3 dB. & the **TILT** increased to 1.5 dB which matched the computer model.



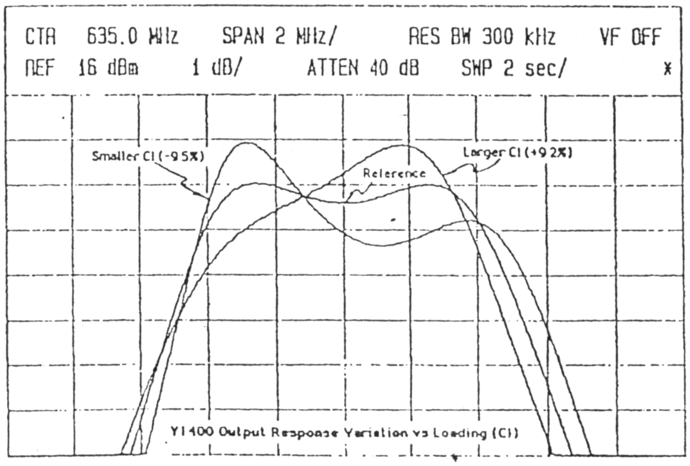
-Figure 16-



-Figure 17-



-Figure 18-



-Figure 19-

-Loading Considerations-

Both the computer model & the Y1400 cavity were terminated in 50+J0 loads. Normally tetrode amplifiers such as the Y1400 can readily handle load VSWRS, as high as 2:1. However, this is only true as long as the load line length is fairly short so that new settings of the **LOADING (Cl)** & **SECONDARY (L-sec)** controls will again restore the previous bandwidth & ripple. But once the load line becomes overly long such that the output impedance exhibits a one half wavelength change (or more) in impedance when tuning across the $\mathbf{f_1}$-$\mathbf{f_2}$ bandwidth, there's not much that can be done to maintain the response shape except possibly the use of a low VSWR circulator or isolator. Even so, the power variation will still approach the limit condition of $VSWR^2$. So even a 1.2:1 VSWR will exhibit a 1.44:1 power variation for a constant current tetrode. Therefore, it's always best to keep the load line as short as possible in order to hold load VSWR problems in check.

-Conclusion-

Learning & mastering the techniques for tuning the four (4) output circuit adjustments used to optimize double tuned output circuits is both easy & rewarding. Mastery comes when you can predict exactly what's going to happen before you 'turn the handle" & rewarding is when your friends are impressed with your prediction.