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**Gary E.J. Bold, ZL1AN:** g.bold@auckland.ac.nz

TEEBAL designs and/or investigates high-pass TEE transmatches. Matches are computed with respect to 50 ohms. Reactive loads may be specified. Inductor losses are included, and power lost in the inductor is calculated. Both capacitor and inductor values can be varied interactively while viewing SWR, and the input impedance of the transmatch shown as series resistance plus reactance.

## 1 Initialisation

TEEBAL may be initialised in one of two ways.

1. If "Automatic" mode is initially selected, you'll be prompted for

   - load resistance in ohms,
   - a load reactance in ohms, (+ve inductive, -ve capacitive)
   - a characteristic impedance in ohms,
   - a frequency in MHz,
   - an inductor Q value.

   A transmatch will be designed, using the lossless design equations, approximately satisfying these parameters. See later for explanations, and what you can do next. The operating screen will then appear.

2. If "Manual mode" is initially selected, you'll be prompted for parameter values

   - $C_1$ and $C_2$ in pF,
   - $L$ in uH,
   - Inductor $Q$,
   - load resistance in ohms,
   - load reactance in ohms, (+ve inductive, -ve capacitive)
   - frequency in MHz.

   If `<enter>` is given for $C_1$ and/or $C_2$ values, 100 pF will be used.
   If `<enter>` is given for Inductor $Q$, one million (effectively infinite) will be used.

   The operating screen will then appear.

## 2 The Operating Screen

### Appearance

At the right, the function of various keys is explained.

| | |
|---|---|
| left/right arrows | Vary the value of $C_2$ down and up by $\delta$C. |
| up/down arrows | Vary the value of $C_1$ down and up by $\delta$C |
| f3 | Set $\delta$C to 0.1 pF |
| f4 | Set $\delta$C to 1 pF |
| f5/f6 | Vary the coil inductance down/up in 0.1 $\mu$H steps. |
| f7/f8 | Vary the load resistance down/up in 1 $\Omega$ steps. |
| Z,X | Vary the load reactance down/up in 1 $\Omega$ ohm steps. |
| f10 | Show characteristic impedance,percentage of input power lost in inductor, voltages across capacitors, minimum possible value of load reactance. |
| ESC | Stop the program. |
| END | Re-start the program immediately. |
| f1 | Show this help screen. |

Above this, the selected load resistance, reactance, and operating frequency in MHz are shown.

At the top left of the screen, the current values of $L$, $C_1$ and $C_2$ (input and output capacitors) are shown. These are immediately updated in response to the arrow keys as indicated above. Below, the current SWR (standing wave ratio with respect to 50 ohms) and current input impedance of the transmatch are shown. Resistive and reactive components are shown separately. *Positive* and *negative* reactance are *inductive* and *capacitive*, respectively.

If a transmatch is designed by TEEBAL itself, (first initialisation option) AND the $Q$ of the inductor is FINITE, the calculated parameters will NOT give an EXACT match (There are no simple design equations which take account of inductor losses). However, the match will be close, and the "true" matching values of the two capacitors can be found by empirical adjustment with the arrow keys. Near the matching point, you'll find that

- Changing $C_1$ predominantly varies the *reactive* component,
- Changing $C_2$ predominantly varies the *resistive* component.

of the input impedance. The match can be adjusted by monitoring *either* the input resistance and reactance (easier when far away from a match) or the SWR (easiest when close to a match). Even when changing the capacitors in steps of 0.1 pF (after pressing f3), an "exact" match cannot generally be obtained to the 4 significant figures of SWR displayed. However no SWR meter can display to this accuracy anyway, and a match to 2 decimal places is close enough.

When a close match has been obtained (or at any time) pressing f10 shows

- the percentage of power currently lost in the transmatch; thus, 4% means 4 watts dissipated if 100 watts is input,
- the current characteristic impedance of the transmatch, as;
  - a *normalised* value (with respect to 1 $\Omega$, the design algorithm uses this)
  - an *un-normalised* value wrt 50 $\Omega$, the actual value used.
- The *rms* voltage developed across $C_1$ and $C_2$ for 100 watts input; The mimumum (most negative) permitted value of load reactance for this value of characteristic impedance.

If the input power is NOT 100 watts, the voltages shown across each capacitor, $V_c$, must be scaled by $V_c\sqrt{P/100}$, where

$V_c$ is the voltage shown on the screen,
$P$ is the actual power.

Thus, if the power input is 400 watts, the capacitor voltages shown must be *doubled*.

## 3 Details of Specifying the Design.

- For initial design, choose the option that lets TEEBAL design the transmatch for you. You then have to specify only the characteristic impedance ($R_0$), the coil $Q$, the load impedance and operating frequency.
- If the load is resistive, or has a *positive* reactive component, you must specify a characteristic impedance which is *larger* than the larger of 50 Ω *or* the load resistance.
- If the load has a *negative* reactive component, you will have to specify an even larger value than this - the output capacitor has to be able to compensate. If your entered value is too small, the minimum acceptable value will be shown, and you'll be prompted for another.
- To get the "equal reactance" design (capacitors identical) for a purely resistive load, choose the value of the characteristic impedance as the load resistance plus 50 ohms.
- For "reasonable" capacitor values, and to give some adjustment leeway, specify a characteristic impedance somewhat greater the minimum.
- Increasing $R_0$ *decreases* the value of capcitors required, but *increases* transmatch losses for a given $Q$.

## 4 Specifying and Changing the Load Impedance

- The load is specified by its SERIES equivalent circuit, that is, a resistance in series with a reactance. INDUCTIVE reactance is positive, CAPACITIVE reactance is negative. Resistance and reactance are entered separately.

  Either can be subsequently varied.

  Load RESISTANCE can be increased/decreased with f7/f8. Load REACTANCE can be increased/decreased with Z/X.
- If the REACTANCE is changed, the value of $C_2$, the output capacitance, is automatically changed to compensate, and immediately reflected in the new value shown on the screen.
- making the reactance more POSITIVE (inductive), DECREASES $C_2$. making the reactance more NEGATIVE (capacitive), INCREASES $C_2$.
- In either case, the MATCH DOES NOT CHANGE - if the tuner is matched, it will stay matched. Note that there is a MAXIMUM NEGATIVE value for the reactance (shown when f10 is pressed) which cannot be exceeded. At this value, the output capacitance is infinite, and if it goes more negative than this, an INDUCTOR would be required. TEEBAL does not cope with this, and you wouldn't want it either.

  Thus, if the load specified has a more negative reactance than this critical value, a LARGER value of R0 (characteristic impedance) must be selected (you'll have to re-start the program) or you can alternatively increase the inductor value using f6 at this point to increases R0.
- If the load RESISTANCE is changed, the bridge WILL become unbalanced. The changed situation is not shown until either capacitance is subsequently changed with the arrow keys. The bridge must now be re-balanced.

## 5 Theory

The match is computed by considering the TEE match as two L matching units back-to-back. The input L is matched to an output "characteristic impedance", R0, which can be thought of as a "virtual resistance" seen at the centre of the transmatch. The output L is matched to a source having R0 as its resistance. The two resulting L inductors are combined in parallel to give the overall inductance required in the transmatch.

For resistive loads, theory shows that R0 MUST be larger than the larger of the load resistance OR the system source resistance (here 50 ohm).

Selecting R0 close to (but greater than) the larger of these will always give LOWER transmatch losses, but LARGER capacitor values, and LOWER voltages across them.

A LARGER R0 gives LARGER values of inductance and SMALLER capacitors, but with HIGHER voltage across them.

The design equations are:

X$C_1$ = sqr(50*(R0 - 50)) - reactance of input capacitor X$C_2$ = sqr(RL*(R0 - RL)) - reactance of output capacitor XL1 = (50*R0)/X$C_1$ XL2 = (RL*R0)/X$C_2$ XL = XL1 // XL2 - reactance of inductance.

These equations don't account for finite inductor Q, the effect of which is modelled as a resistance in series with the inductor. A closer match can always be found by adjusting the capacitor values. However, if R0 is too close to its limiting (lower) value, an exact match may not be possible. Increase the inductance value and try again.

The power dissipated in the transmatch is found by performing series to parallel transformations (using Bold's equations) on the inductor and its series loss resistor, and the load and series output capacitance. The ratio of the resulting equivalent parallel resistances is equal to the inverse ratio of the power dissipated in each. The total power in both is normalised to 100 watts. This is exact, and not just an application of the approximate expression

k = (sqr(R0/50 - 1) + sqr(R0/R2 - 1))/Q

The voltage across a capacitor is found using

Vc = I*Xc where I is rms current through a capacitor of reactance Xc.

I1 (input capacitor current) is found by assuming that this causes 100 watts to be dissipated in 50 ohms. I2 (output capacitor current) assuming that this causes 100 watts to be dissipated in the load resistance. The relations are

V$C_1$ = sqr(P*(R0 - 50)) V$C_2$ = sqr(P*(R0 - R2)) where P = input power

## 6 Typical Parameters Values:

"Receiving spaced" capacitors are adequate for "reasonable" loads for powers up to 100 watts or so. Assume that such capacitors break down (arc) when greater than about 500 volt rms is developed across them.

Minimum values of such capacitors are typically 10 - 20 pF. Maximum values of such capacitors are typically 100 - 350 pF. On lower frequency bands, sections of multi-ganged capacitors can be connected in parallel, when the capacitance values ADD.

Inductance values required typically vary from 10 uH (80 metres) to 1 uH or less (10 metres).

A good quality (air-spaced, at least one coil diameter from metal) inductor will have Q of up to 200. About 100 is a good all-round value. Toroidal inductors wound on cores may have Q's of 50 or less.

## 7 Design Example

Start the progrm: When asked if TEEBAL is to design the transmatch, enter "y" or just ¡enter¿. Enter

load resistance = 200 ohms characteristic impedance = 1000 ohms frequency, MHz = 3.7 Inductor Q = 100

The operating screen will immediately display these values:

L = 6.765 uH $C_1$ = 197.4 pF $C_2$ = 107.5 pF SWR = 1.0636

Adusting $C_1$ and $C_2$ will allow the SWR to be reduced to 1.0010, with

$C_1$ = 199.2 pF $C_2$ = 104.7 pF

Pressing f10 then shows that 6.25inductor, and the resulting characteristic impedance = 983 ohms. This is much larger than the load, so if we have extra capacitance capability, we can try reducing this.

Lower L to 5.065 uH (f5). Re-balance, and find

$C_1$ = 289.9 pF $C_2$ = 172.2 pF SWR = 1.0006

Pressing f10 again shows that 4.17characteristic impedance has dropped to 491 ohms. If we have even more capacitance, we could reduce it further by decreasing L again.