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Original Research

COMPARATIVE ANALYSIS OF SOME MATCHING NETWORKS

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ABSTRACT

Resonant and Magnetically coupled transformer impedance transformation techniques are reviewed. The resonant matching has the advantage of the relatively high primary inductance. While magnetically coupled transformer has efficiency Independent of power enhancement ratio (PER), E. Efficiency equations for the two techniques were studied.

Keywords: Matching networks, Networks, Analysis, Efficiency, Impedance, Resonance, Magnetic, Transformer.

INTRODUCTION

Impedance matching is the practice of attempting to make output impedance of a source signal equal to the input impedance of the load to which it is connected, in order to maximize the power transfer and minimize reflections from the load (Wikipedia, 2007; Amanogowa, 2006).

A single LC section may be used to perform impedance matching. In some cases, it may be desirable to cascade several such sections to enhance the efficiency (Ichiro *et al*., 2002; Sophocles, 2004; Leeson, 1999; Boon, 2006).

Resonant impedance transformation has the advantage of relatively high primary inductance to achieve the highest efficiency. But its efficiency depends on power enhancement ratio (PER), which decrease with increase in PER (Ichiro *et al.*, 2002).

Magnetically coupled transformer has the advantage of PER-Independent efficiency but its disadvantage is low primary inductance (Ichiro *et al.,* 2002).

MATERIALS AND METHOD

Analytical method was employed to study the efficiency equations for the two techniques. Numerical values of the efficiencies for the techniques were calculated and compared.

Resonant impedance transformation

The efficiency (η) equation of the network for a single section is

$$\eta = 1 - \frac{\sqrt{E-1}}{Q_{ind}} \qquad (1)$$

and the efficiency of the network for multi-section transformation with s segments is given as

$$\eta = \left(1 - \frac{\sqrt{E^{\frac{i}{s}}-1}}{Q_{ind}}\right)^{s} \qquad (2)$$

where s is the number of stages and E is the power enhancement ratio (PER). For any matching network, we can define the power enhancement ratio (PER) E as the ratio of the radio frequency, RF, power delivered to the load with a transformation network in place P_{trans} to the power delivered to the load for the same sinusoidal input voltage source when it drives the load directly P_{direct}, i.e.

$$E = \frac{P_{trans}}{P_{direct}} = r\eta \quad (3)$$

where r is the transformation ratio. The impedance transformation ratio, r, is defined as

$$r = \frac{R_{Load}}{R_{in}} = 1 + Q_L^2 \quad (4)$$

where R_{Load} and R_{in} are the load and its transformed impedance at Port-1 and Q_L is the loaded quality factor of the single section LC impedance transformation network , shown in figure 1.

$$Q_L = \frac{R_{LOAD}}{\omega L_P} \quad (5)$$

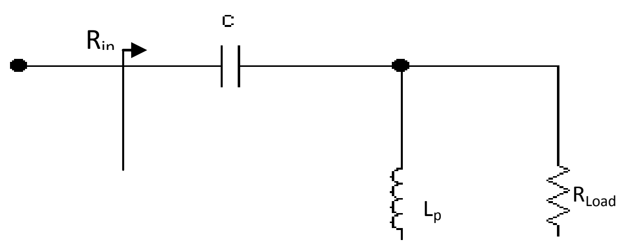

Figure 1: Single section LC impedance transformation network

The resonant condition is

$$\frac{1}{\omega c} = \omega L_P \quad (6)$$

$$\omega L_P = \left(\frac{1}{\sqrt{E} - 1} - \frac{1}{Q_{ind}}\right) R_{Load} \quad (7)$$

Where ω is the angular frequency and L_p is the primary inductance. For a given inductor quality factor $Q_{ind,}$ there is an upper bound on the maximum achievable PER E, where the efficiency η becomes zero. This maximum achievable PER , E_{max} is

$$E_{Max} = 1 + Q_{ind}^2 \quad (8)$$

Equation (8) provides an upper bound on the value of E in a single inductor-capacitor section.

Magnetically coupled transformer impedance transformation

The transformer efficiency η is the ratio of power delivered to the load P_{load} to the total power delivered into port-1 of the network P_{total}.

$$\eta = \frac{P_{Load}}{P_{total}} \quad (9)$$

Using the optimum L_1, the maximum efficiency is 2 .

$$\eta = \frac{1}{1 + 2\sqrt{\left(1 + \frac{1}{Q_1 Q_2 K^2}\right)\frac{1}{Q_1 Q_2 K^2}} + \frac{2}{Q_1 Q_2 K^2}} \quad (10)$$

Where Q_1 and Q_2 are quality factors of the primary and the secondary inductors and can be calculated in terms of R_1 and R_2 respectively as shown in figure 2.

$$Q_1 = \frac{\omega L_1}{R_1}, \quad Q_2 = \frac{\omega L_2}{R_2} \quad (11)$$

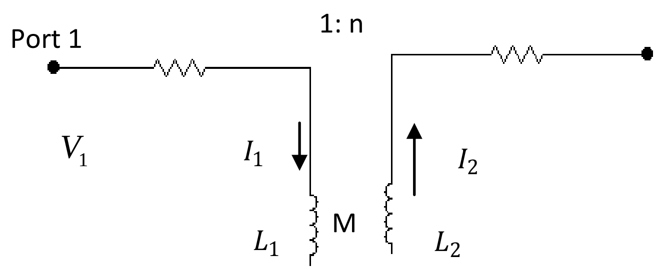

Figure 2: Transformer Model

The voltages V_1 and V_2 of the coupled transformer are related to the currents by

$$n = \sqrt{\frac{L_2}{L_1}} = \frac{I_1}{I_2} = \frac{V_2}{V_1} \quad (12)$$

and

$$M = K\sqrt{L_1 L_2} \quad (13)$$

where M is the mutual inductance, K is the coupling factor and n is the turn ratio between the primary and secondary coils.

To calculate the transformer turn ratio n for a desired PER, E, we use:

$$E = \frac{\eta n^2 Q_1}{\left(\frac{Q_1}{K^2} + Q_2\right)} \quad (14)$$

and

$$n = \sqrt{\frac{E\left(\frac{Q_1}{K^2} + Q_2\right)}{\eta Q_1}} \qquad (15)$$

The optimum value of L resulting in the highest possible efficiency η is

$$\omega L_1 = \frac{1}{1+A^2}\frac{AR_L}{n^2} \qquad (16)$$

Where

$$A = \frac{1}{\sqrt{\frac{1}{Q_2^2} + \frac{Q_1}{Q_2}K^2}} \qquad (17)$$

The maximum efficiency equation (10) shows that it can be maximized using a K as close as possible to unity (Ichiro *et al.*, 2002).

RESULTS AND DISCUSSION

Based on the analysis of the resonant impedance transformation network, the values of efficiency η and power enhancement ratio E for several different values of Q_{ind} using equation (1) were calculated (Table 1) and plotted as shown in Figure 1 for a single LC section . And also the values of ωL_P and power enhancement ratio E for different values of Q_{ind} using equation (7) were calculated and plotted in Figure 2.

Table 1: Calculated values of efficiency, power enhancement ratio E and inductor quality factor Q_{ind}

η %	E	E	E	E	E	E
0	26.00	101.00	401.00	901.00	1601.00	2501.00
10	21.25	82.00	325.00	730.00	1297.00	2026.00
20	17.00	65.00	257.00	577.00	1025.00	1601.00
30	13.25	50.00	196.00	442.00	785.00	1226.00
40	10.00	37.00	145.00	325.00	577.00	901.00
50	7.25	26.00	101.00	226.00	401.00	626.00
60	5.00	17.00	65.00	145.00	257.00	401.00
70	3.25	10.00	37.000	82.00	145.00	226.00
80	2.00	5.00	16.00	37.00	65.00	101.00
90	1.25	2.00	5.00	9.00	17.00	26.00
Q_{ind}	5	10	20	30	40	50

Figure (1) shows a plot of η versus E for several different Q_{ind} which shows that efficiency decreases with increasing E. And it shows that for a given inductor quality factor Q_{ind}, there is an upper bound on the maximum achievable E, where the efficiency η becomes zero. This maximum achievable PER, E_{max}, was found to be equation (8) which provides an upper bound on the value of E in a single LC section. However, it should be noted that the efficiency would drop to zero as we approach this E_{max}, making this bound unachievable.

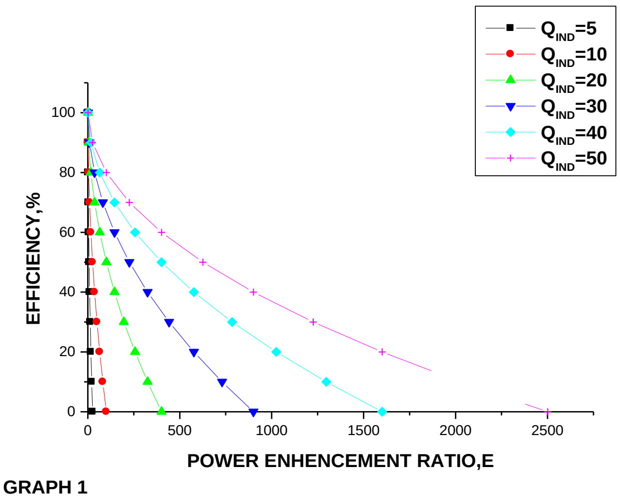

Figure 1: Efficiency versus PER and inductor Quality factor Q_{ind}.

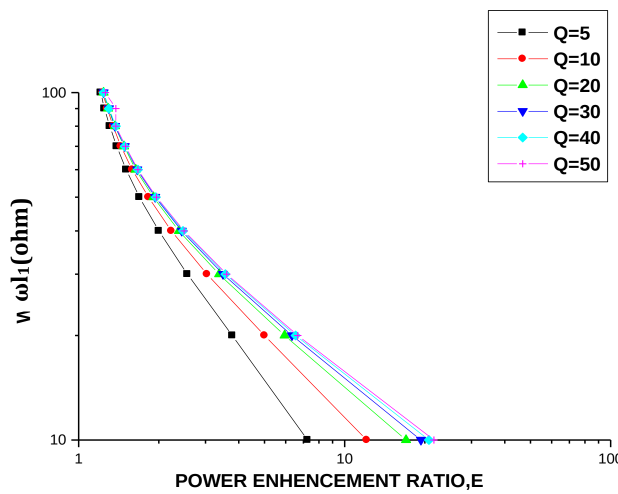

Figure 2: Inductor reactance versus PER and Q

In Figure 2, which is a plot of ωL_P versus E for a given Q_{ind}, the result shows that for a given Q_{ind}, ωL_P decrease with increase in PER, E.

For multi-section transformation with s segments, efficiency η and E were calculated for different Q_{ind} and s using equation (2) and plotted in Figures 3a and 3b, which show that efficiency decreases with increasing E, but not as in single section.

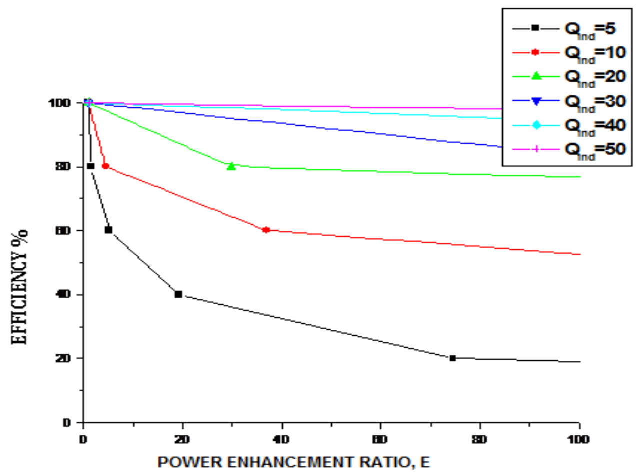

Figure 3a: Efficiency versus PER and Q_{ind} for multisection (s=2) resonant network

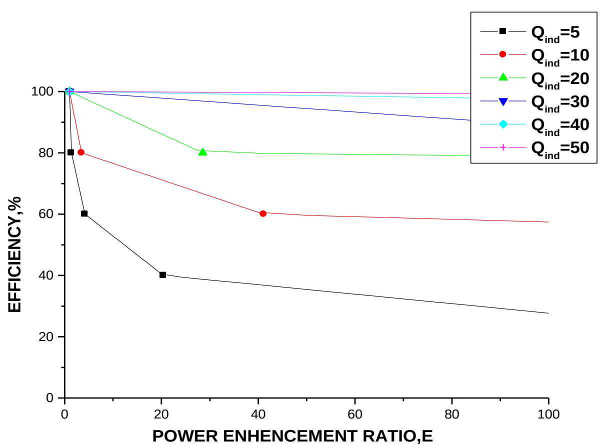

Figure 3b: Efficiency versus PER and Q_{ind} for multisection (n=3) resonant network

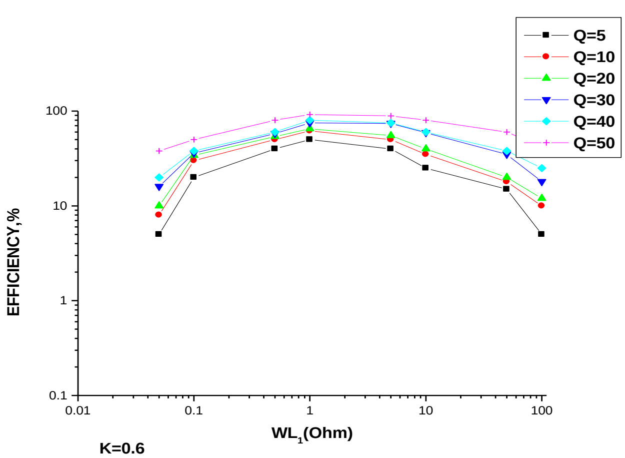

Figure 4a Efficiency versus Primary inductor reactance and inductor quality factor Q

For magnetically coupled transformer, the values of ωL_1, η and Q_1 were calculated using the equations (10), (11) and (16) for several values of K and Q_2 and were plotted in Figures 4a and 4b.

It was shown that transformer efficiency is reduced when the reactance of the inductor is above or below the optimum value determined by equation (16).

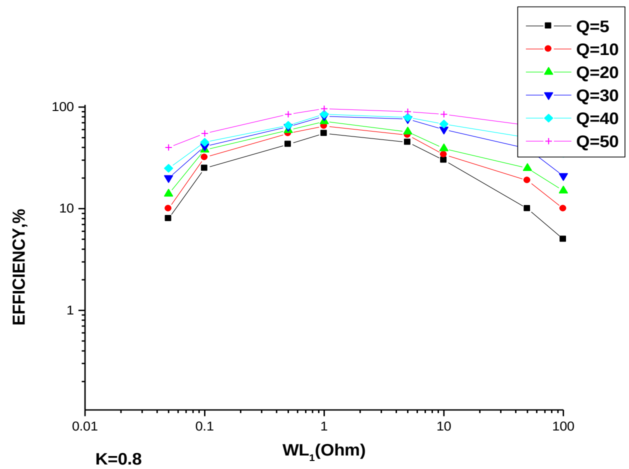

Figure 4b: Efficiency versus Primary inductor reactance and Q

Figures 5a, 5b and 5c for show plots of calculated values of η versus primary inductor quality factor Q_1 for several secondary inductor quality factor Q_2 and coupling factor K for a transformer, based on Tables 5a, 5b and 5c, respectively, using equation (10).

Table 5a: Calculated values of primary inductor quality factor, efficiency and Q_2 for K=0.2 of a transformer

Q_1	η %	η %	η %	η %	η %	η %
1.00	5.00	8.00	11.00	20.00	23.00	27.00
20.00	38.00	50.00	61.00	66.00	70.00	73.00
40.00	50.00	61.00	70.00	75.00	78.00	80.00
60.00	57.00	67.00	75.00	79.00	82.00	83.00
80.00	61.00	70.00	78.00	82.00	84.00	85.00
K=0.2	Q_2=5	Q_2=10	Q_2=20	Q_2=30	Q_2=40	Q_2=50

Table 5b: Calculated values of primary inductor quality factor, efficiency and Q_2 for K=0.6 of a transformer

Q_1	η %	η %	η %	η %	η %	η %
1.00	25.00	36.00	48.00	55.00	59.00	63.00
20.00	72.00	79.00	85.00	87.00	89.00	90.00
40.00	79.00	85.00	89.00	91.00	92.00	93.00
60.00	83.00	87.00	91.00	92.00	93.00	94.00
80.00	85.00	88.00	92.00	93.00	94.00	95.00
100.00	86.00	90.00	93.00	94.00	95.00	95.40
K = 0.6	Q_2=5	Q_2=10	Q_2=20	Q_2=30	Q_2=40	Q_2=50

Table 5c: Calculated values of efficiency, primary inductor quality factor Q_1 and Q_2 of transformer

Q_1	η %	η %	η %	η %	η %	η %
1.00	42.00	54.00	64.00	70.00	73.00	75.00
20.00	82.00	87.00	91.00	92.00	93.00	94.00
40.00	87.00	91.00	93.00	94.00	95.00	96.00
60.00	89.00	92.00	94.00	95.00	96.00	96.40
80.00	91.00	93.00	95.00	96.00	97.00	97.00
100.00	92.00	94.00	96.00	96.40	97.400	97.20
K = 1	Q_2=5	Q_2=10	Q_2=20	Q_2=30	Q_2=40	Q_2=50

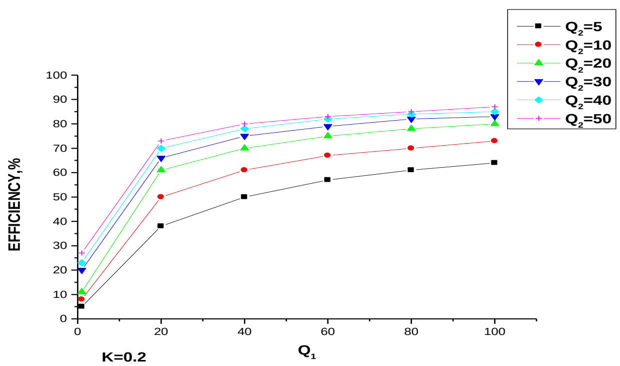

Figure 5a: % Efficiency versus primary inductor quality factor, Q_1 for K = 0.2

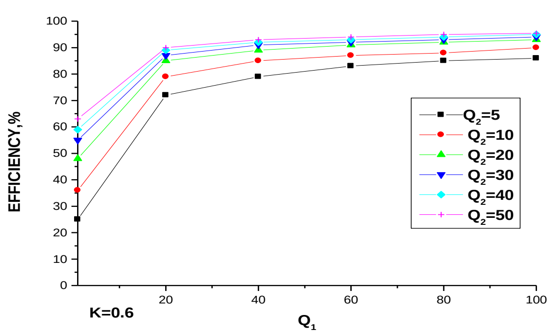

Figure 5b: % Efficiency versus primary inductor quality factor, Q_1 for K = 0.6

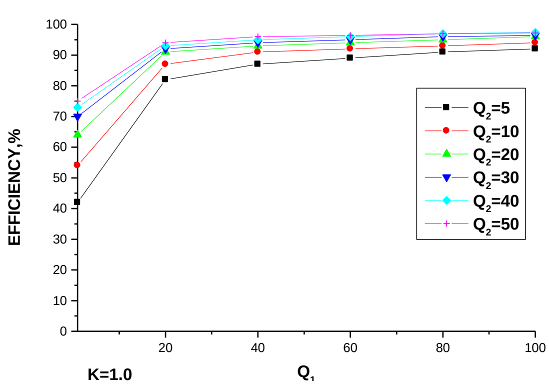

Figure 5c: % Efficiency versus primary inductor quality factor, Q_1 for K = 1.0

The analysis shows that, in a magnetically coupled transformer the efficiency η, does not depend on the E, unlike the resonant LC matching circuit. It also shows that primary inductor reactance decreases with increase in E for resonant impedance matching and also the efficiency decreases with increasing E.

CONCLUSION

This study revealed that resonant matching network has high efficiency but it decreases with increase in power enhancement ratio, E. The study also showed that magnetically coupled transformer has low primary inductance which makes it less efficient.

CONFLICT OF INTEREST

No conflict of interest declared.

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