Abstract – This paper discusses the design and implementation of broadband matching network for RF power amplifiers. The realization of impedance matching network using microstrip lines and lumped components is carried out. Simulation results for broadband impedance matching network are presented and analyzed. Measured and simulation results for a developed 2W RF Power amplifier are also presented.

I. INTRODUCTION

One of the most important design aspects of RF power amplifier is impedance matching network. Any impedance mismatch in the source or load side leads to reduced device gain and large reflected power. As the rating of the power amplifier increases, any loss of power due to impedance mismatch will reduce the efficiency of the power amplifier drastically. The reflected power also affects the reliability of the device in use and complicates its thermal management [1].

Impedance matching network is the key for complete transfer of power to the load. For any RF amplifier, impedance matching network should provide matching over the complete frequency band of interest. The two element impedance matching network and stub matching techniques are not very effective over a wide band of frequencies, since they provide matching over a very narrow band [2]. The other disadvantage of the two element matching network is that the frequency at which the matching takes place is very sensitive to the inductor and capacitor tolerances.

II. BROADBAND MATCHING

Synthesis of impedance matching networks for RF amplifiers using equiripple approximation have been reported [3]. Though this method uses less number of elements, the improvement observed in the input reflection coefficient and output reflection coefficient is not significant over the band of frequency.

In the multiple LC section approach of broadband matching, the matching elements are chosen so that the matching network has a very low Q. As Q is inversely proportional to bandwidth, the bandwidth of the matching network increases by restricting the component values to low Q region. Fig.1 shows the constant Q contours on the Smith Chart [4-5].

Fig.1 Constant Q contours on Smith Chart [4]

Fig.2 shows the graphical technique to find the values of inductances and capacitances avoiding the higher Q regions on a Smith chart. To match $\Gamma_L$ (load reflection coefficient) to 50Ω, constant reactance contours are traversed within the bounds of the real axis and the constant Q contour. Each hop from the real axis to the constant Q contour and back to the real axis adds a LC section. The number of hops required to reach from $\Gamma_L$ to
the 50Ω point decide the number of LC sections required for impedance matching.

### III. NETWORK REALIZATION

To design a broadband matching network for a given frequency band from \( f_1 \) to \( f_2 \), a constant Q contour is drawn on the Smith Chart. The value of Q for 3dB bandwidth is given by

\[
Q = \sqrt{\frac{f_1 f_2}{f_2 - f_1}} \quad \ldots \quad (1)
\]

Inductor and capacitor values calculated using the Smith chart generally result in non-standard values. It is difficult to get the standard values of both inductor and capacitors that are close to the calculated values. This problem is overcome by using standard lumped capacitors and using microstrip lines to realize the inductances. This method gives freedom in choosing the inductor values.

A thin microstrip line can be used to realize an inductor of given value. Equation 2 gives the length of the microstrip line to realize an inductor of value \( L \).

\[
I = \frac{\lambda_0}{2\pi} \tan^{-1} \left( \frac{\omega L}{Z_0} \right) \quad \ldots \quad (2)
\]

In the above equation \( \lambda_0 \) is the effective wavelength and \( Z_0 \) is the characteristic impedance of the microstrip line. Similarly, a thick microstrip line can be used to realize capacitors. However, this technique is not very effective for realizing large values of inductors and capacitors [2-4].

Fig.3 shows a broadband multiple LC sections matching network using lumped inductors and microstrip line.

### IV. DESIGN OF MATCHING NETWORK FOR 2W AMPLIFIER

A single LC section and a multiple LC section input and output matching networks are designed for a 2W power amplifier SPB2026Z available from Sirenza [6]. The S-parameters for SPB2026Z at 1.8 GHz are

\[
\begin{align*}
S_{11} &= 0.91179\angle 167.85^\circ \\
S_{21} &= 1.07238\angle 75.26^\circ \\
S_{12} &= 9.42 \times 10^{-3} \angle -5.84^\circ \\
S_{22} &= 0.88524\angle 167.42^\circ 
\end{align*}
\]

The unmatched device has a very small gain with relatively large values of input and output reflection coefficient.

The single LC section and multiple LC section matching networks are designed using the graphical method and optimized using AWR Microwave Office software for 1.75-2 GHz band. The designed networks are shown in Figs.4 and 5. In the design, capacitors with standard values are used while the length of the microstrip lines used as inductors is optimized to obtain the desired results.

Fig.4 Single LC section input and output matching network

Fig.5 5-LC section matching network (a) input matching network, (b) output matching network.

Fig.6 shows the input and output matching comparison between unmatched, single-LC section and 5-LC section matched power amplifier.

From Fig.6 it is seen that there is a significant improvement in matching on both input and output side of the power amplifier. For the single LC section, the input reflection coefficient (\( \Gamma_i \)) is less than -10dB for 150MHz from 1.82 to 1.97GHz while the 5-LC section matching shows an improvement of -5dB and gives \( \Gamma_i \) less than -15dB for 150MHz from 1.81GHz to 1.95GHz. Similarly, there is an improvement of at least -10dB for the output reflection coefficient (\( \Gamma_o \)). The output reflection coefficient for 5-LC section matching is less than -20dB for the complete 1.87-2GHz band indicating that only 1% of the power is reflected at the output.
is due the better matching achieved. Simulation results thus confirm that the multiple LC sections can be used as a broadband matching network.

V. TEST RESULTS FOR 2W AMPLIFIER

To verify the simulation results and to have a better understanding of the implementation issues a 2W power amplifier is fabricated using SPB2026Z with a three element (T) matching network. A 0.8mm thick glass epoxy Printed Circuit Board (PCB) is used to realize the circuit. Fig. 8 shows the photograph of the fabricated 2W power amplifier module.

Gain, input and output reflection coefficient of the fabricated 2W amplifier module were measured using a network analyzer. During the testing it was observed that parasitic inductances and capacitances cause unwanted resonances causing a shift in the frequency band over which gain is desired.

Fig.8 2W power amplifier module-3.3cm×3.3cm

Gain, input and output reflection coefficient plot

Fig.9 3-element matching (T) network- gain, input and output reflection coefficient plot

The gain for unmatched device is 0.6dB, while the single LC section gives a maximum gain of 14.14dB with a -0.5dB bandwidth of 200 MHz from 1.8 to 2GHz. The 5-LC section matching gives the best results with a maximum gain of 15dB and a -0.5dB bandwidth of 250MHz from 1.75 to 2GHz. The improvement in gain and bandwidth in 5-LC section matching
obtained for gain (|S_{21}|^2), input reflection coefficient (S_{11}) and output reflection coefficient (S_{22}) after the necessary modifications. The gain as seen on network analyzer has maximum value of 10.7dB at 1.9GHz and varies from 9.5dB at 1.7GHz to 10.1dB at 2GHz. The difference in gain as seen on the network analyzer and the simulation results can be partly accounted by the cable and connector losses.

The power amplifier module was also tested for its output power and power added efficiency (PAE) using a RF source and spectrum analyzer. The power amplifier was powered with a 5V supply and an input RF power of 21.5dBm was given. The current drawn by the module was observed to be 1.02A. The measurements for gain and output power at various frequencies along with the calculated values of power added efficiency are tabulated in Table 1. The cable losses are already considered in these measurements.

**Table 1 Measurement results for 2W PA**

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Gain (dB)</th>
<th>Output Power (dBm)</th>
<th>PAE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.7</td>
<td>10.3</td>
<td>31.8</td>
<td>26.9</td>
</tr>
<tr>
<td>1.8</td>
<td>11.0</td>
<td>32.5</td>
<td>32.1</td>
</tr>
<tr>
<td>1.9</td>
<td>11.7</td>
<td>33.2</td>
<td>38.2</td>
</tr>
<tr>
<td>2.0</td>
<td>9.5</td>
<td>31.0</td>
<td>21.9</td>
</tr>
</tbody>
</table>

On similar lines, broadband matching network for 15W and 30W amplifiers have been designed. Detailed test results for the 2W, 15W and 30W amplifiers using multiple LC section matching networks will be presented in the conference.

**VI. CONCLUSION**

It is observed that the multiple LC section matching network provides matching over a wide frequency band, with more freedom in the choice of the components. The simulation results obtained for the broadband matching network show a great improvement in the input and output reflected power with only 1% of the power getting reflected in the frequency band for which the network is designed.

While designing printed circuit board for implementing the power amplifiers care must be taken to reduce parasitic inductances and capacitances.

**VII. REFERENCES**