# ACTIVE BROADBAND IMPEDANCE TRANSFORMATIONS USING DISTRIBUTED TECHNIQUES

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## ABSTRACT

A circuit concept is derived which allows impedance transformations to be performed over extremely broad bandwidths. The transformation is obtained by coupling two or more identical distributed amplifier circuits in parallel by the use of a common input or output line. The circuit technique can be used where broadband impedance matching is important such as laser diode drivers or antenna matching in broadband receivers and transmitters. The circuit technique is demonstrated for a 1:2 impedance transformation over a 2 to 20GHz bandwidth by results presented for a fabricated amplifier.

## INTRODUCTION

The need often arises in microwave circuit design to provide an impedance transition between an impedance mismatched source and load. One method of accomplishing this transition passively is to use a quarter wavelength transformer. The performance of the transformer is however very dependent on the designed circuit wavelength and therefore only narrowband impedance transformations are possible. A method of providing this transition actively is to use reactively tuned amplifiers which are matched to different impedances at input and output. The bandwidth of these circuits is, however, limited by the potential of the reactive matching network which is at most 2 octaves. Recently[1], interest has been renewed in distributed amplifiers due to their extreme bandwidth potential ( as much as 4-5 octaves[2]) and easy producibility utilizing Monolithic Microwave Circuit Technology. Distributed techniques have been used to build broadband mixers[3] and frequency multipliers[4] as well as amplifiers[5-11]. Currently, the technology of distributed amplifiers has been focused around providing amplification between a source and a load with the same impedance. A novel technique is described here which exploits the bandwidth potential of distributed amplifiers in formulating a distributed impedance transformation amplifier.

## GENERAL THEORY

The concept of distributed amplifiers revolves around the circuit shown in Fig. 1. The intent of this circuit is to combine active elements and passive components in such a manner as to form transmission line-like structures thereby taking advantage of the properties of transmission lines, e.g., large bandwidth and gain flatness. As can be seen in Fig. 1, an input synthetic transmission line is formed by combining the shunt input capacitance of the active element with an appropriate amount of series inductance. The amount of added inductance is determined by the desired characteristic impedance at the input. Gain is realized by synthesizing a second transmission line containing the amplified signal at the output using the combined output capacitance of the active element, $C_o$, and an added capacitance, $C_a$, as the shunt element. The value of $C_a$ and the series inductance of the output line, $L_o$, are determined by stipulating that the phase velocities of the input and output synthetic transmission lines be equivalent, or[1]

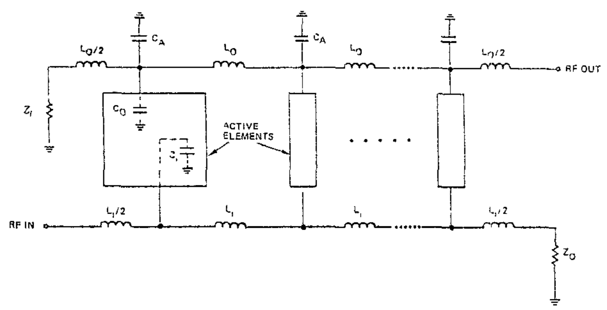


Figure 1. General circuit used to realize a distributed amplifier.

$$v_{pi}=[1-(\frac{f}{f_{ci}})^2]^{\frac{1}{2}}/[L_i C_i]^{1/2} \tag{1a}$$

$$=v_{po}$$

$$=[1-(\frac{f}{f_{C_o}})^2]^{1/2}/[L_o(C_o+C_a)]^{1/2} \tag{1b}$$

where

$$f_{C_i}=\frac{1}{\pi(L_i C_i)^{1/2}} \tag{2a}$$

$$f_{C_o}=\frac{1}{\pi[L_o(C_o+C_a)]^{\frac{1}{2}}} \tag{2b}$$

and f is the frequency. This condition must be satisfied in order for the input wave to be coupled in phase to the output wave through the active elements along the length of the amplifier.

The characteristic impedances of the input and output synthetic transmission lines are also dependent on the values of the added inductance and capacitance and are given approximately by

$$Z_i=(\frac{L_i}{C_i})^{1/2}[1-(\frac{f}{f_{C_i}})^2]^{1/2} \tag{3a}$$

and

$$Z_o=(\frac{L_o}{C_o+C_a})^{-1/2}[1-(\frac{f}{f_{C_o}})^2]^{1/2} \tag{3b}$$

If the input and output impedances of the amplifier are chosen to be equivalent than simultaneous solution of equations (1) and (3) results in $L_i = L_o$ and $C_t = C_o + C_a$. These equations form the basis of the determination of the necessary additive element values in a distributed amplifier.

## IMPEDANCE TRANSFORMATION TECHNIQUES

### Line Impedance Variation (LIV)

A simple method of obtaining a small impedance transformation from the input to the output is to adjust the elements along the input and output amplifier lines to reflect the desired impedances while adhering to the condition described by Eq. (1). Substituting the impedance transformation given by

$$Z_t = rZ_o \tag{4}$$

into equations (1) and (3) yields

$$C_a = rC_t - C_o \tag{5a}$$

and

$$L_o = L_t / r \tag{5b}$$

Although adequate for small impedance transformations, the technique becomes inappropriate for larger transformations for several reasons. For small values of $r$ ($r < 0.33$ to $0.25$), the value of the added capacitance $C_a$ necessary for the transformation in equation 5 will become negative precluding the possibility of transformations of magnitude greater than 1:3 to 1:4. Another problem with this technique is that the output or input transistor may be largely mismatched because of the impedance it must see in order to create a particular characteristic impedance along the output or input synthetic transmission line. The resulting circuit will have reduced circuit gain and increased noise figure and in many cases may even become unstable. Yet another problem will result for large transformations in that the large inductors and small capacitors ( for large characteristic impedance ) or small inductors and large capacitors ( for small characteristic impedance ) necessary to perform the required transition may become hard to realize physically. These extreme values of the circuit elements also cause the circuit to become more sensitive to process variations. All of these problems are eliminated by the technique introduced in this paper.

### Constant Line Impedance(CLI)

The generalized circuit concept is described in Fig. 2. The two possible types of impedance transformations(step up and step down) between the input and output are shown separately in the diagram. Figure 2a describes the distributed CLI impedance transformation amplifier which is matched to a larger impedance at the output than at the input. In this structure, the input signal is split between $n$ parallel distributed amplifiers all having an input impedance of $Z_o$ determined by the value of the series element $Z_c$ and the shunt capacitance of a single active element. The resulting input impedance of the entire circuit is thus equal to $Z_o/n$. All of the parallel amplifiers have a common output line with the passive elements along this line, $Z_a$ and $Z_b$, adjusted so that the impedance and phase velocity of the collective output line match those of each of the input lines. There are thus $n+1$ synthetic transmission lines, $n$ input lines and 1 output line, all having identical properties. The impedance at the output is equal to the characteristic impedance of the single output line, $Z_o$.

The circuit of Fig. 2b achieves signal amplification between a source with a larger impedance than the load. All of the coupled distributed amplifiers have the same input line whose characteristic impedance, $Z_o$, is set by the value of $Z_c$ and the parallel combination of the $n$ shunt active elements. The value of $Z_d$ and $Z_e$ are adjusted so that the phase velocity and characteristic impedance of the output lines match those of the common input line. The output lines of the amplifiers are attached in parallel at the output resulting in an output

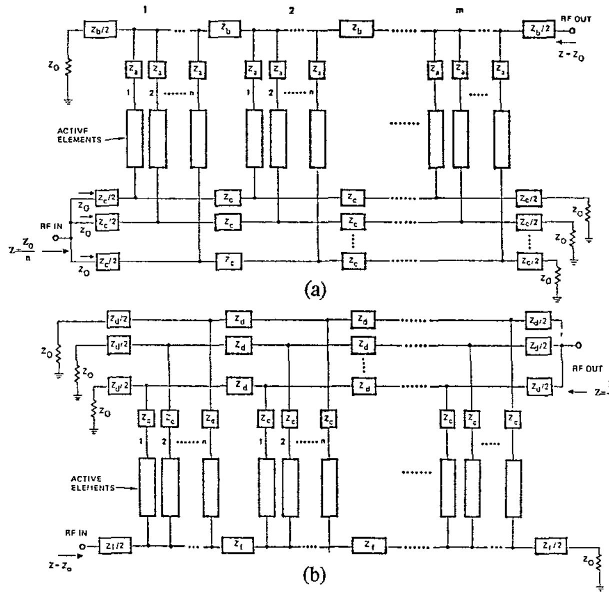

Figure 2. Generalized circuit topology of the CLI distributed impedance transformation amplifier introduced in this paper. Amplifier configurations are shown for (a) an impedance multiplication and (b) an impedance division.

impedance of $Z_o/n$. Thus, as in the previous circuit, there are $n+1$ synthetic transmission lines all having the same properties, however, in contrast, there are now $n$ output lines and 1 input line resulting in impedance reduction at the output.

## SIMULATED COMPARISONS

A comparison of the LIV method and the CLI method was performed through simulation for a 3:1 impedance transformation. The simulated LIV circuit, illustrated in Fig. 3a, consisted of 9 cascode pairs. The output drain line of the LIV circuit was terminated in a 17 Ω load resistance and the input line was terminated in a 50 Ω resistance reflecting the characteristic impedances of each of the synthesized transmission lines necessary to yield the desired 3:1 transformation. The comparable CLI circuit is illustrated in Fig. 3b. In this case, all of the synthesized transmission lines are terminated in identical load resistances of 50 Ω. For each simulation the transistor s-parameters used were measured from Rockwell foundry 0.5 μm gate length and 180 μm gate width FETs. Both circuits utilize the same number of devices and thus the same total device area. The lengths of the microstrip transmission line elements were calculated in each case according to equations 1 to 5 and then optimized for highest gain and best output match.

Figure 4 presents the simulated results of the circuits shown in Fig. 3. The CLI technique yields an approximate improvement in gain of about 2dB and a return loss improvement of between 5 and 15 dB over the LIV technique across the circuit bandwidth. Additionally, the asymmetries of the LIV circuit shown in Fig. 4a make it more difficult to realize physically than the CLI circuit shown in Fig. 4b. For this reason impedance transformations larger than 3:1 must be performed using the CLI technique. Stability is also improved using the CLI technique. The LIV circuit becomes conditionally stable at around 12.5 GHz whereas the CLI circuit remains unconditionally stable with a stability factor greater than 3 for all frequencies. It should be mentioned that the bandwidth of the circuit of 4b is slightly reduced due to the additional shunt capacitance introduced by the CLI method on the input synthetic transmission line for step down transformations. This capacitance can be reduced and the bandwidth correspondingly increased by use of a capacitor placed in series with the shunt transistors as demonstrated by Chase and Kenan[8] for high gate periphery power

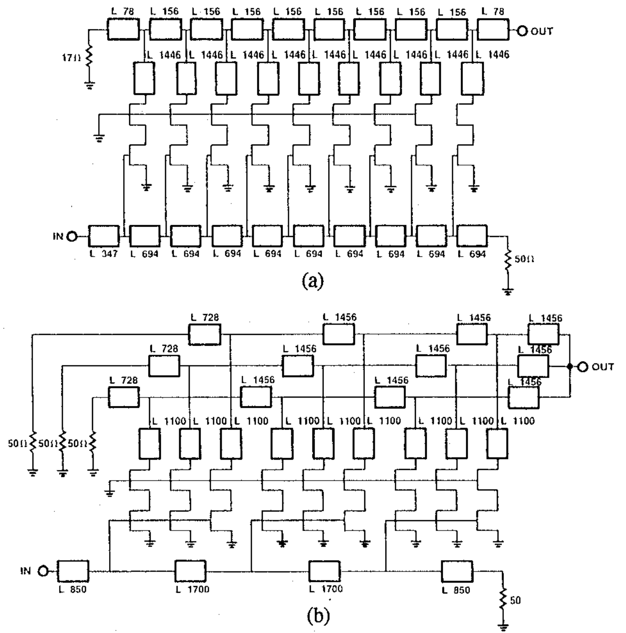


Figure 3. Circuit topologies and element values for a 3:1 wideband distributed impedance division using (a) the LIV method and (b) the CLI method.

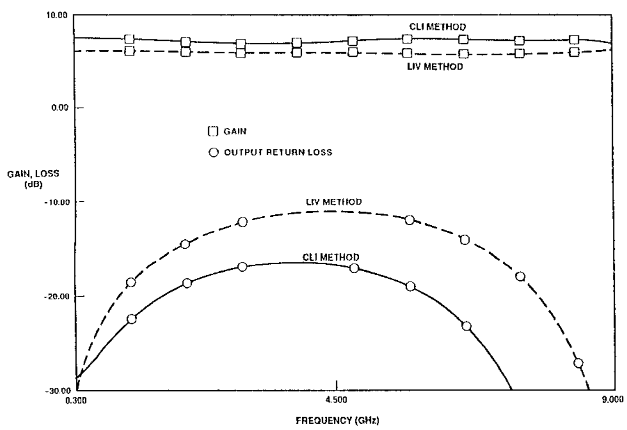


Figure 4. Simulated responses for the circuits shown in Fig. 3.

distributed amps. For step up impedance transformations, the CLI technique results in increased bandwidth because of the reduced series inductance on the input line.

Impedance transformations of any ratio can be obtained by combining both the LIV and the CLI techniques simultaneously, e.g., a 2.5:1 transformation can be obtained by performing a 5:4 transformation using the LIV method on each of the arms of a 2:1 CLI impedance divider.

## RESULTS

A circuit which demonstrates the transformation described by Fig. 2a was designed, simulated and fabricated. The impedance transformation occurs between an input impedance of 25 ohms and an output impedance of 50 ohms. Optimized circuit element values are shown in Figure 5. The active element is a cascode connected pair of 0.5 μm gate length GaAs FETs. The passive elements are transmission lines whose lengths are adjusted to yield maximum gain and minimum return loss. The transistor widths for the devices used in the simulations are 180um which was determined to be the optimum width for the desired 2-20GHz bandwidth. The common source FET was designed using a split source to bring out the gate connection( as in the pi fed structure)whereas the common gate device has gate connections on both sides to bypass capacitors. The novel dual FET structure results in minimized parasitic capacitances and easy incorporation into the circuit layout.

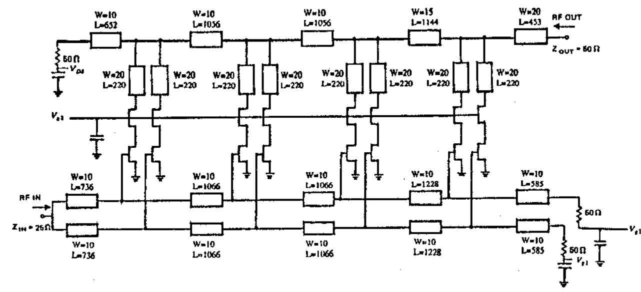


Figure 5. Circuit diagram and element values for a circuit designed and fabricated using the CLI technique.

A photograph of the completed circuit is shown in Fig. 6. The circuit was probed on wafer with a Cascade Probe, and circuit s-parameters were measured with an HP8510 network analyzer. The measured input and output impedance of the amplifier are shown on the normalized 50 Ω smith chart shown in Fig. 7. The chart clearly illustrates that the amplifier input impedance remains close to the value of 25 Ω whereas the output impedance is approximately 50 Ω over the freq. range from 2 to 19 GHz. In order to obtain a true plot of gain and return loss, the s-parameters measured in a 50 Ω environment must be translated via circuit simulation to reflect a 25 Ω input termination. The measured and translated parameters were very similar except for the value of the input return loss which is significantly less for a 25 ohm input termination than for the 50 ohm termination of the measuring system as expected. The resulting translated parameters are shown in Fig. 8. The circuit obtains a gain of 9±1dB from 4 to 20GHz and a return loss at the input and output of more than 12dB from 2 to 19GHz. The DC drain bias was 150mA at 4V for a total DC power consumption of 600mW. The 1dB compression point was measured to be greater than 20dBm at 9GHz.

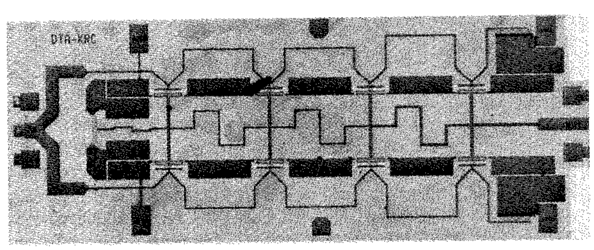

Figure 6. Photograph of the fabricated wideband CLI distributed impedance transformation amplifier.

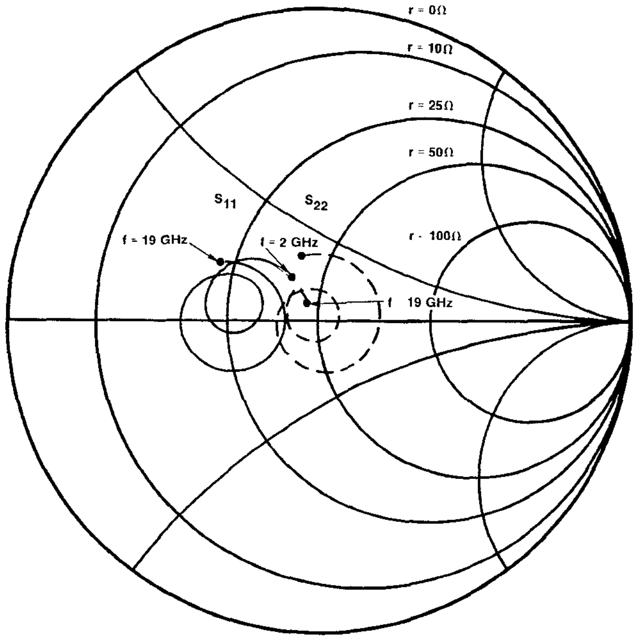


Figure 7. Measured input and output impedances of the impedance transformation amplifier plotted on a 50 Ω smith chart from 2 to 19GHz.

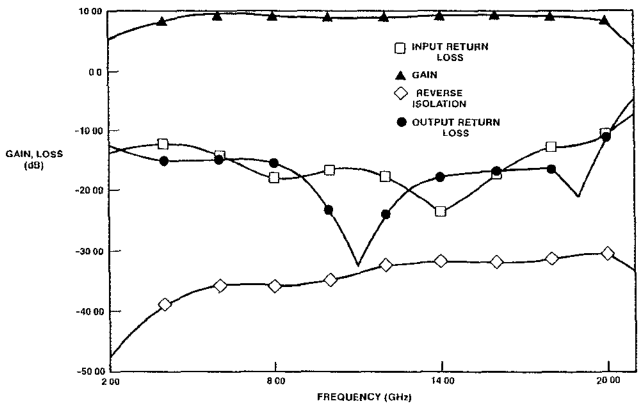


Figure 8. Measured s-parameters of the distributed impedance transformation amplifier terminated in a 25 Ω input impedance and a 50 Ω output impedance.

## CONCLUSION

An active circuit design technique which allows impedance transformations over extremely broad bandwidths has been described and demonstrated. Potential uses for the distributed impedance transformation amplifier include wideband RF semiconductor laser and optical modulator driver circuits (impedance division), broadband front end receiver circuits which match antennas with characteristic impedances greater than 50 ohms to 50 ohm circuits ( impedance division ), and wideband transmitters where the transmitting antenna impedance does not match the circuit impedance (impedance multiplication). In general the idea can be applied to almost any matching application where wide bandwidths are required.

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