HIGH POWER AMPLIFER PROTOTYPE FOR WIRELESS POWER TRANSMISSION RECEPTION

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ABSTRACT

The design of high power microwave amplifier involves three main components; namely the two port network, input matching and output matching circuits. All the components are formed by establishing the scattering parameters, followed by selecting appropriate reflection coefficient for the matched circuits. The characteristics of the design are based on Wireless Power Transmission prototype for the Solar Power Satellite. These are 13 dB gain, 16 dBm output power and narrowband frequency of operation of 2.45 GHz ISM (Industrial, Scientific and Medical) standard. The active element of the amplifier is Gallium Arsenide microwave transistor operating at 2.2 to 2.6 GHz. By using a mathematical computation software, the load and source reflection coefficients are found to be 0.213 and 0.19-0.23i, respectively. These agree well with manual calculations performed earlier. The reflection coefficients formulations have been derived from that of the transducer gain (G_T) for developing the input and output matching circuits.

KEYWORDS
Wireless power transmission, high power amplifier, solar power satellite reception.

1.0 INTRODUCTION

The conceptual of transmitting power without the use of wire or any physical medium has been introduced by Nikola Tesla about a century ago [1]. Researchers all over the world hardly study the potential of Wireless Power Transmission (WPT) to realize the idea of collecting sun energy through solar panels located in the space or known as Solar Power Satellite. In the development of Solar Power Satellite, a few stages are involved in order to collect the sun energy from space and then transmit it to the earth grounds. Amplification system is one of the stages in transmitting power where it is located at the transmitting side [2].

The amplifier is a main component in the microwave section of a wireless power transmission along with the filter, antenna and oscillator. This is shown in Figure 1. When designing microwave amplifiers, the task is to select the suitable technique to ensure the desired characteristics such as gain, stability, loses and interference can be achieved.

This paper will focus mainly on the amplifier design technique for the WPT prototype transmitter. The gain characteristic at the desired operating frequency of 2.45 GHz is studied. The amplification stage of WPT done by ISAS Japan produced an impressive gain characteristic of about 13dB [3]. In the designing process, in order to achieve the required characteristic, the selection of reflection coefficient is crucial in achieving the desired results. One technique has been successfully developed in determining the reflection coefficient. The technique is derived from the power gain equation and is discussed in this paper.

2.0 AMPLIFIER DESIGN TECHNIQUE BASED ON REFLECTION COEFFICIENT

It is very difficult to select the value of reflection coefficient in order to get the ideal characteristic of the amplifier design. The source and load reflection coefficients are chosen to achieve the maximum gain and perfect match as well as to ensure stability. Amplifier design typically begins with the selection of high performance of two-port transistor. This is followed by the design of the input matching circuit M1 and output matching circuit M2 (Figure 2).

The design technique proposed starts with a systematic mathematical solution aided by a graphical method to determine the source and load reflection coefficients for a specified gain. The power gain equation is very helpful in solving the selection of load and source reflection coefficients. Figure 2 illustrates the block diagram of a microwave amplifier and the different powers used in the gain equation. The transducer power gain G_T, the power gain G_P and the available power gain G_A are defined as follows:

$$G_T = \frac{P_L}{P_{AVS}} = \frac{\text{power delivered to the load}}{\text{power available from source}} \qquad (1)$$

$$G_P = \frac{P_L}{P_{IN}} = \frac{\text{power delivered to the load}}{\text{power input to the network}} \qquad (2)$$

$$G_A = \frac{P_{AVN}}{P_{IN}} = \frac{\text{power available from the network}}{\text{power input to the network}} \qquad (3)$$

The expression of G_T, G_P and G_A can be derived next.

$$G_T = \frac{1-|\Gamma_S|^2}{|1-\Gamma_{IN}\Gamma_S|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \qquad (4)$$

$$G_P = \frac{1}{|1-\Gamma_{IN}|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-\Gamma_{OUT}\Gamma_L|^2} \qquad (5)$$

$$G_A = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{1-|\Gamma_{OUT}|^2} \qquad (6)$$

3.0 SIMULATION WORK PERFORMED AND DISCUSSION OF RESULTS

The power gain G_p and Scattering (S) parameter are functions of the load reflection coefficient Γ_L via the well known formula given below:

$$Gp = \frac{(|S21|)^2 \cdot \left[1-(|P+X\cdot 1i|)^2\right]}{\left[1-\left[\left|S11+\frac{S12\cdot S21\cdot(P+X\cdot 1i)}{1-S22\cdot(P+X\cdot 1i)}\right|\right]^2\right]} \cdot \frac{1}{\left[\,|1-S22\cdot(P+X\cdot 1i)|\,\right]^2} \qquad (7)$$

S_{11}, S_{12}, S_{21} and S_{22} are very useful to model the transistor in the microwave range and completely characterize the behavior of the two-port network [5]. Γ_L is shown in the form of complex numbers (P+Xi). This is to ease the mathematical analysis so that the most suitable value of the desired gain is achieved. In order to obtain the practical values for reflection coefficient of the amplifier circuit, mathematical calculations are done manually as well as using a mathematical software. This focused on a fixed amplifier power gain G_P to achieve the desired 13 dB characteristic. The simulation results will give the best value of Γ_L for the 13dB gain.

There are four different cases in the process of achieving the reflection coefficients Γ_L and Γ_S.

Case I – The value of the imaginary number is fixed to Xi = 0.0007i. Figure 3 shows the simulated result with maximum gain = 575 and reflection coefficient Γ_L = 0.213+0.00007i.
Case II - The value of the real number is fixed to P = 0.213. This value is based on the result of case 1. Figure 4 shows the result achieved for the maximum gain = 19.84 and the reflection coefficient $\Gamma_L = 0.213 - 3.5527 \times 10^{-14}$. The value of Γ_L = 0.213 + 0.00007i is then used to calculate the reflection coefficient Γ_S through the G_T,

$$GT = \frac{\left[1-(|Tsb|)^2\right]\cdot(|S21|)^2\cdot\left[1-(|TLa|)^2\right]}{(|1-S11\cdot Tsb|)^2\cdot\left[\left|1-\left(S22+\frac{S12\cdot S21\cdot Tsb}{1-S11\cdot Tsb}\right)\cdot TLa\right|\right]^2} \qquad (8)$$

Case III - The value of imaginary number is fixed to Xi = 0.0008i. Figure 5 shows the result of the maximum gain = 18.51 and the reflection coefficient Γ_S = 0.1455 + 0.008i.
Case IV – The method is similar to case III but with P = 0.1455. Figure 6 shows the result of the maximum gain = 19.57 and the reflection coefficient Γ_S = 0.1455 – 0.238i.
The step in case I to IV forms one technique in determining the best value of reflection coefficient for the desired 13 dB maximum gain of the amplifier. Various other combinations of reflection coefficients can be performed until the exact value of the desired gain is achieved. Table 1 shows the values of transducer gain G_T with the appropriate reflection coefficient.

The amplifier gain in Table 1 is defined from the power gain equation. The S parameter of the transistor has been used. The load and source reflection coefficients derived from the power gain equation are then used to design the M1 and M2 circuits and integrated with the selected transistor. Then, the complete amplifier circuit consisting of the M1 and M2 circuits and the two-port network are simulated using an electromagnetic simulation software. The simulated gain is found to be in good agreement with the mathematical computation of Table 1. Figure 7 illustrates the simulation result of the amplifier circuit. The output gain is 13.05 dB at the corresponding operating frequency of 2.45 GHz.

The amplifier gain of G_T can also be calculated by using mathematical equation. After combining the input matching circuit and output matching circuit with two-port transistor, the simulation performed resulted in an achieved gain of 13.05 dB. This result is similar to that obtained using the power gain equation formula of equation (8). Now, the S parameter of G_T is no longer taken from the transistor but measured from the whole amplifier circuit including M1, M2 and the two port networks. The S parameter of the transistor is different after combining the input and output matching circuits and the transistor. The S parameter for the whole circuit is defined by the following formula:

$$S_{11} = \frac{Z - Z_0}{Z + Z_0} \qquad (9)$$

where Z Z_{in} Z_S and

$$Z_{in} = \frac{-Z_{in}(1+\Gamma_{in})}{\Gamma_{in}-1} \quad (10)$$

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L} \quad (11)$$

and S_{11} S_{22}.

The S parameters obtained for the full circuit operating at 2.45 GHz frequency are

S_{11} = -0.261 + 0.0398i S_{12} = 0.0376 +0.016i

S_{21} = 1.85 +4.06i S_{22} = 0.114 – 0.325i

The mathematical software has been used to plot the graph of G_T as shown in Figure 8. Figure 7 is the simulation result of G_T using an electromagnetic simulation software. Figure 8 is the simulation result obtained from mathematical computation using an mathematic simulation software. The shape of the plotted graphs for both G_T are very similar to each other, with the exception of a slight difference at the operating frequency of 2.45 GHz. G_T = 13 dB in Figure 7 while it is 12.9 dB in Figure 8. The slight difference could be due to the consideration of other factors such as the internal reflection coefficient in the electromagnetic simulation software.

4.0 CONCLUSION AND RECOMMENDATIONS

This paper has shown one technique for selecting the appropriate values of the source and load reflection coefficients to achieve a desired maximum gain of 13 dB. This technique can also be applied to designing the matching circuits whereby the values of Γ_S and Γ_L from the power gain equation can be used to determine the stability factor of the amplifier circuit.

5.0 ACKNOWLEDGEMENTS

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TABLE 1

Γ_L	Γ_S	G_T
0.213	0.19-0.23i	13dB
0.213-0.008i	0.8 +0.008i	20.3dB
0.221+0.0019i	0.062+0.008i	10.5dB
0.221+0.0019i	0.062-0.28i	10.7dB

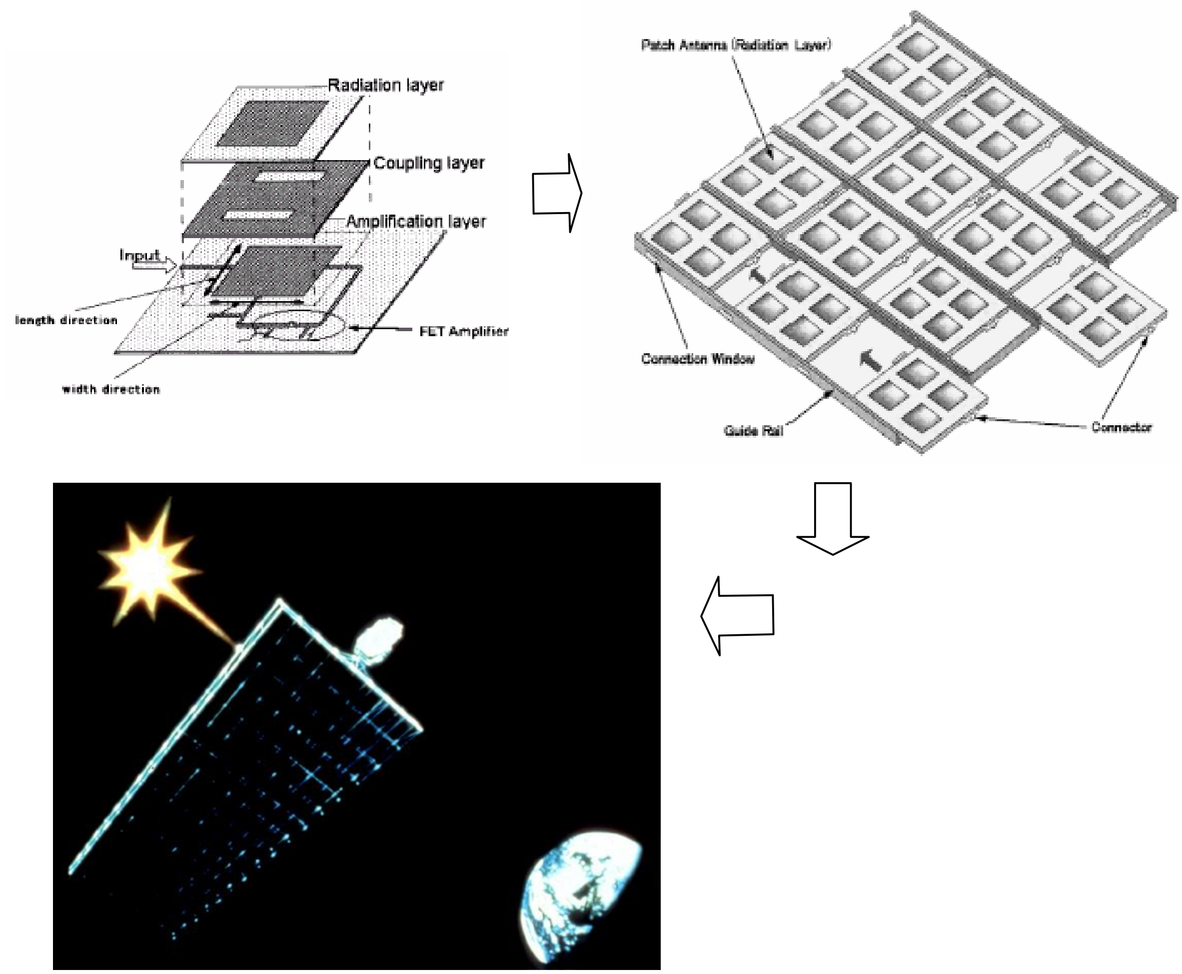

FIGURE 1: Amplification layer of Solar Power Satellite [3]

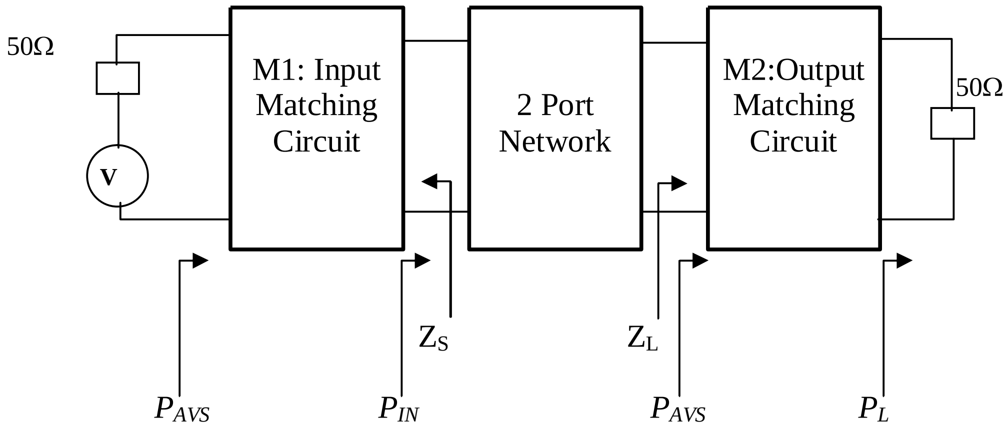

FIGURE 2: Ideal Microwave Amplifier Block Diagram.

$$\frac{(|S21|)^2\cdot\left[1-(|P+X\cdot 1i|)^2\right]}{\left[1-\left[\left|S11+\frac{S12\cdot S21\cdot(P+X\cdot 1i)}{1-S22\cdot(P+X\cdot 1i)}\right|\right]^2\right]}\cdot\frac{1}{\left[\left|1-S22\cdot(P+X\cdot 1i)\right|\right]^2}$$

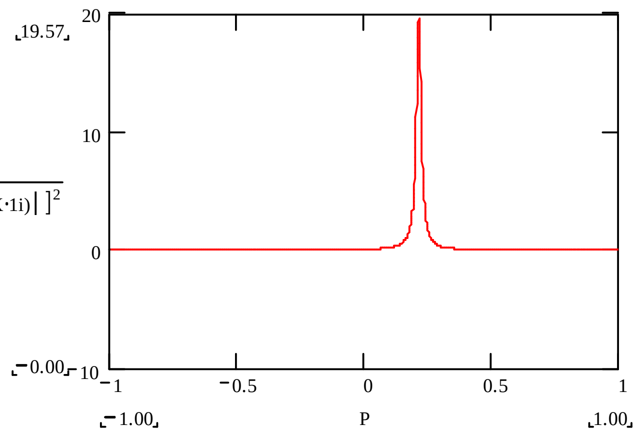

FIGURE 3: G_P versus Real Value of Load Reflection Coefficient, using MathCAD.

$$\frac{(|S21|)^2\cdot\left[1-(|Pa+Xa\cdot 1i|)^2\right]}{\left[1-\left[\left|S11+\frac{S12\cdot S21\cdot(Pa+Xa\cdot 1i)}{1-S22\cdot(Pa+Xa\cdot 1i)}\right|\right]^2\right]}\cdot\frac{1}{\left[\left|1-S22\cdot(Pa+Xa\cdot 1i)\right|\right]^2}$$

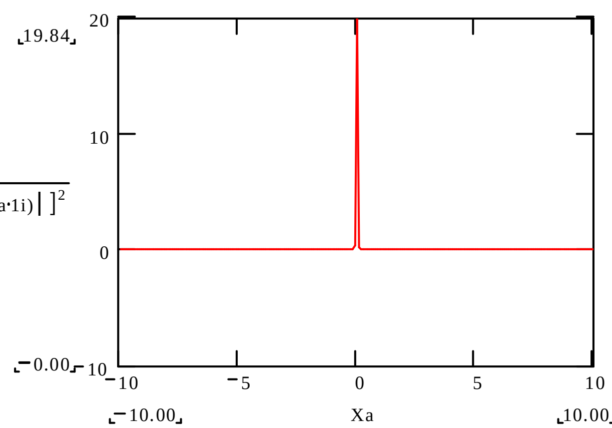

FIGURE 4: G_P versus Imaginary Value of Load Reflection Coefficient, using MathCAD.

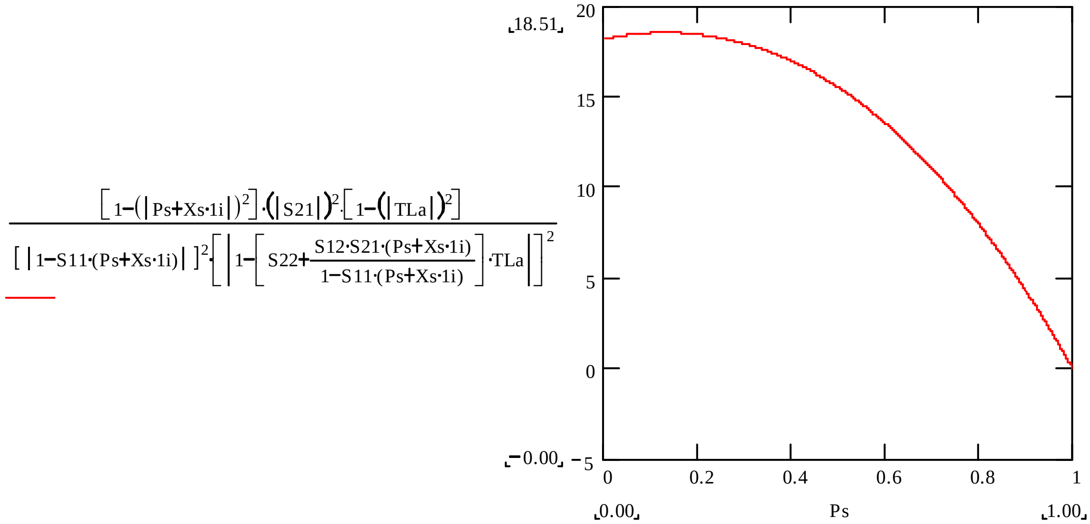

FIGURE 5: G_T versus Real Value of Source Reflection Coefficient, using MathCAD.

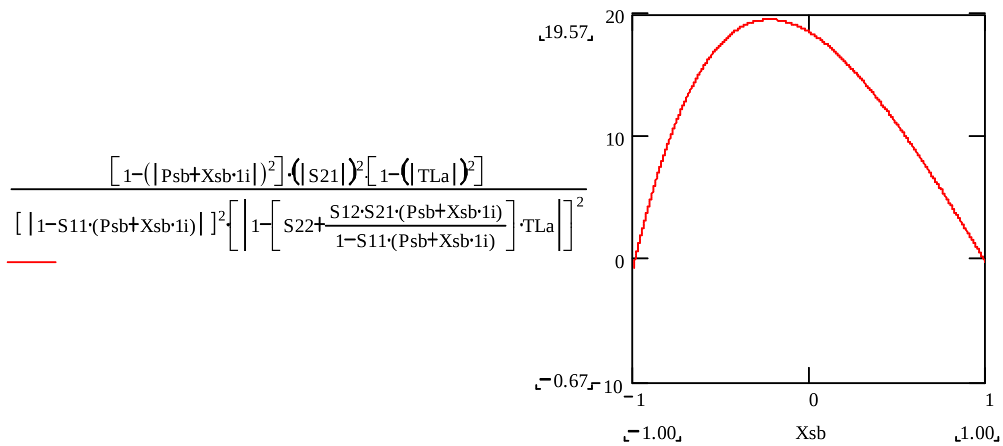

FIGURE 6: G_T vs Imaginary Value of Source Reflection Coefficient, using MathCAD.

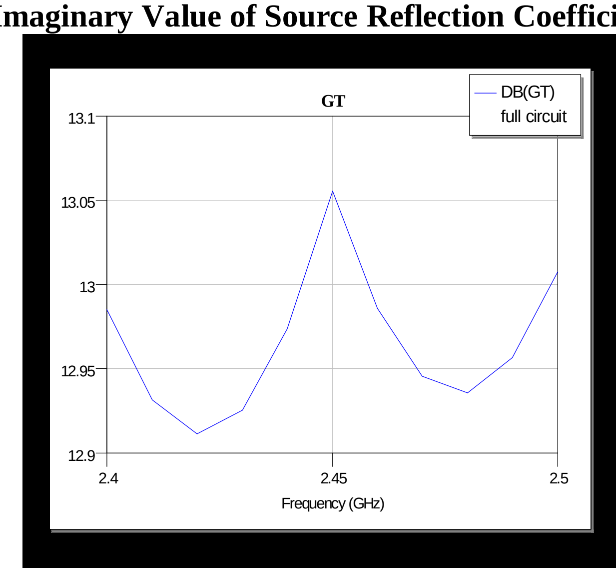

FIGURE 7: G_T Response using (a) Electromagnetic Simulation Software.

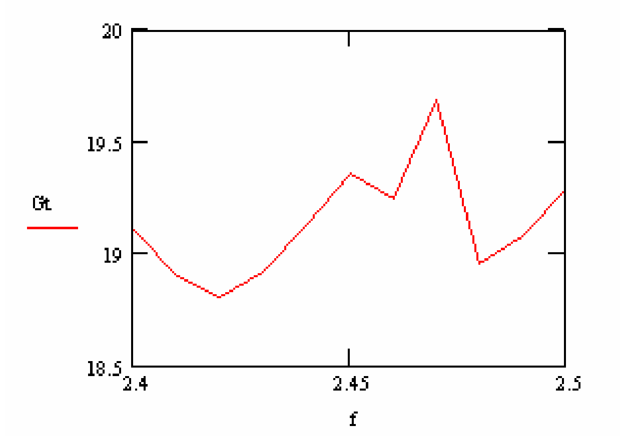

FIGURE 8: G_T Response using MathCAD.