A Design of Unilateral Microwave Transistor Amplifiers in the CCITL System

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Abstract

A design of the unilateral microwave transistor amplifier in the conjugately characteristic impedance transmission line (CCITL) system the T-chart is reported. It is observed that the unilateral property of the transistor is maintained after integrating to the CCITL system. The variations of the gain factors calculated using the characteristic conductance approach (CC) with the argument ϕ that is the argument of the line characteristic impedance are compensated for one another resulting in the constant unilateral transducer power gain G_{TU}. Series single-stub tuning is employed for circuit matching. It is observed from numerical results that stub lengths for both input and output matching networks decrease with the argument ϕ but the variations of the distance between the stub and port for both networks are different. These results indicate that a better design may be achieved by selecting the proper argument ϕ.

1. Introduction

The conjugately characteristic-impedance transmission lines (CCITLs) are a class of transmission lines that have been widely studied [1-3]. CCITLs are lossless and possess conjugate characteristic impedances of wave propagating in opposite directions. Examples of CCITLs are reciprocal lossless uniform lines, nonreciprocal lossless uniform lines, and exponentially tapered lossless nonuniform lines, and periodically loaded lossless lines operated in passband.

Power gains, stability, noise, and VSWR are ones of important design considerations in microwave transistor amplifiers. The analysis and design have been widely performed in the Z_0 system using the Smith chart, where Z_0 is the characteristic impedance of associated standard transmission lines of interest. To simplify the design, unilateral devices (S_{12} = 0) are usually employed since they are unconditionally stable when $|S_{11}|$ and $|S_{22}|$ < 1. In this paper, the design and analysis of unilateral microwave transistor amplifiers in the system of CCITLs to achieve maximum power gains are reported. The power gains computed using the CC approach of unilateral amplifiers are discussed [4]. The T-chart that is the graphical tool used in the analysis and design of the amplifiers in the CCITL system [1] is employed to determine appropriate input and output matching networks using reciprocal single-stub series tuners.

This paper is organized as follows. Section II presents the theory of CCITLs and traveling-wave relations for the two-port network integrated with CCITLs in brief. Power gains consideration is discussed in section III. Input and output matching network design using single-stub series tuners associated with T-chart are reported in section IV. Finally, conclusion is provided in Section V.

2. Theory of CCITLs and the Traveling-Wave Relations

In this section, only reciprocal CCITLs which have similar propagation constant β for both incident and reflected waves are discussed. On a CCITL, the traveling wave equations for the phasor voltage $V(z)$ and the phasor current $I(z)$ can be written as

$$V(z) = V^+ e^{-j\beta z} + V^- e^{j\beta z} \tag{1}$$

$$I(z) = \frac{V^+}{Z_0^+} e^{-j\beta z} - \frac{V^-}{Z_0^-} e^{j\beta z} . \tag{2}$$

Note that V^+ and V^- are defined as the amplitudes of incident and reflected voltage waves referenced as z = 0, respectively. In (2), Z_0^+ and Z_0^- are defined as characteristic impedances of CCITLs entering and leaving port respectively, which are complex conjugate of one another. For convenience, let us define $Z_0^{\pm}$ as

$$Z_0^{\pm} = |Z_0| e^{\mp j\phi} , \tag{3}$$

where $|Z_0|$ and ϕ are the absolute value and the argument of Z_0^-, respectively. In this paper, only *passive* characteristic impedances are considered; i.e., the argument ϕ must lie in the following range [1]:

$$-90° \leq \phi \leq 90°. \tag{4}$$

The manipulation of scattering parameters for the microwave transistor in the CCITL system is carried out using the CC approach [4] for which the normalized incident and reflected waves at each port are defined as

$$a_i = V_i^+ \sqrt{G_0^+} \quad (5)$$

and

$$b_i = V_i^- \sqrt{G_0^+} \;, \quad (6)$$

where i = 1 and 2 represents input and output ports respectively, and G_0^+represents a real part of $1/Z_0^{\pm}$.

The microwave transistor amplifier in a CCITL system is illustrated in Fig. 1. Note that Γ_S, Γ_L, Γ_{IN}, and Γ_{OUT} are source, load, input, and output reflection coefficients, respectively.

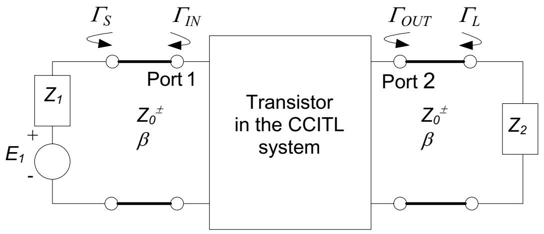

Fig. 1: A microwave transistor amplifier in a CCITL system.

3. Power Gain Considerations of the Unilateral Amplifier in the CCITL System

A two-port device is considered unilateral when S_{12} = 0. Therefore its input and output reflection coefficients are simply S_{11} and S_{22} respectively, and the unconditionally stability is achieved when $|S_{11}|$ and $|S_{22}|$ are less than 1. In this paper, an unconditionally stable transistor is of interest in the design of the microwave amplifier in the CCITL system. It is observed that a unilateral device in a standard Z_0 system still maintains the unilateral property when integrated to the CCITL system. By using a CC approach, the unilateral transducer power gains G_{TU} in the CCITL system can be written as [4]

$$G_{TU} = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2}|S_{21}|^2 \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \;, \quad (7)$$

and can be written as the multiplication of three effective gain factors,

$$G_{TU} = G_S G_0 G_L \;, \quad (8)$$

where

$$G_S = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2} \quad (9)$$

$$G_0 = |S_{21}|^2 \quad (10)$$

and

$$G_L = \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \;. \quad (11)$$

The term G_0 represents the transistor gain while the terms G_S and G_L can be thought of as the input and output gain factors respectively, that represent the gain or loss produced by the matching or mismatching of the input and output circuits. Note that S parameters shown here are in the CCITL system. To determine the variation of these gain factors with the argument ϕ, a test unilateral BJT whose S parameters in a 50 Ω system at common-emitter voltage V_{CE} = 10 V, collector current I_C = 20 mA, and operating frequency f = 1 GHz are $S_{11}^0 = 0.706\angle{-160^\circ}$, $S_{12}^0 = 0$, $S_{21}^0 = 5.01\angle{85^\circ}$, and $S_{22}^0 = 0.508\angle{-20^\circ}$ is employed. The subscript '0' denotes values in a standard Z_0 system. The impedance Z_1, Z_2, and Z_0 are set equally at 50 Ω. Γ_S and Γ_L values are chosen such that the maximum unilateral power gain $G_{TU,max}$ can be obtained and can be shown as

$$\Gamma_S = S_{11}^* \quad (12)$$

and

$$\Gamma_L = S_{22}^* \;. \quad (13)$$

These gain terms are computed and plotted as a function of the argument ϕ as depicted in Fig. 2. Gain variations are observed in all terms, however, they compensate for one another resulting in an overall constant $G_{TU,max}$ = 18.29 dB. This phenomenon is similar to what is reported in the companion paper for a bilateral microwave transistor amplifier [5]. The resulting maximum power gain $G_{PU,max}$ and maximum available power gain $G_{AU,max}$ are also similar to $G_{TU,max}$ for this test set.

4. Design of the Unilateral Amplifier Using Reciprocal Single-Stub Series Tuners

The same test set of S parameters is employed in the design of the unilateral microwave transistor amplifier in the CCITL system. The test circuit composes of Z_1 and Z_2 of equally 50 Ω. The design is carried out for 5 cases at ϕ = -60°, -30°, 0°, 45°, and 60° for comparison. This design in aimed for the maximum power gain therefore the key task is to build the matching network to match the optimal Γ_S and Γ_L shown in (12) and (13) to the source and load impedances, respectively. The variation of S^*_{11} and S^*_{22} values as a function of the argument ϕ are plotted on Γ_S and Γ_L planes respectively, and are shown in Fig. 3 and Fig. 4, respectively. This variation of S parameters indicates that the maximum transducer power gain can be achieved with different designs of matching networks on corresponding locations on Γ_S and Γ_L planes.

The design of input and output matching networks in the T-chart is performed using short-circuited stub series tuners by following the procedures described in [6] and [7]. The design parameters are the distances d_L and d_S, which are the length from the stub to the output and input ports respectively, and the lengths l_L and l_S of the stubs, respectively.

A schematic diagram of the final design of the microwave transistor amplifier is shown in Fig. 5. An example of the T-chart solutions at $\phi = 45^{\circ}$ using single-stub series tuners for the output matching network is shown in Fig. 6. Note that the conjugately characteristic impedance is defined differently from those in the previous work [1] resulting in the different appearance of the T-chart at the same argument ϕ.

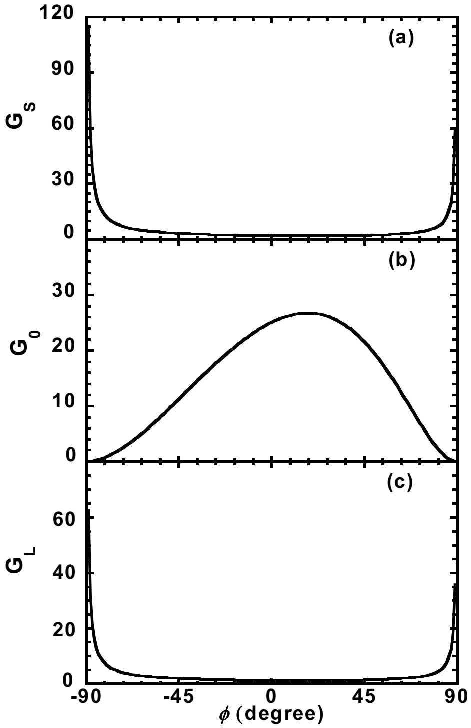

Fig. 2: Gain factors as a function of the argument ϕ for (a) input (b) transistor and (c) output.

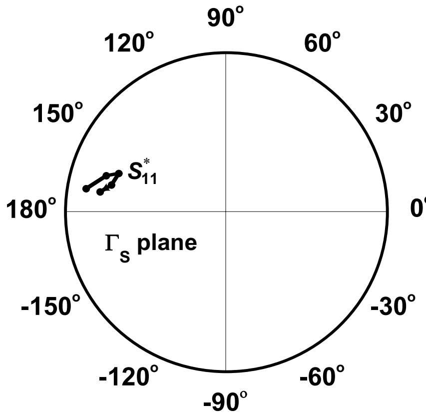

Fig. 3: S^*_{11} values are plotted on the Γ_S plane. The arrow indicates the direction in the increase of the argument ϕ.

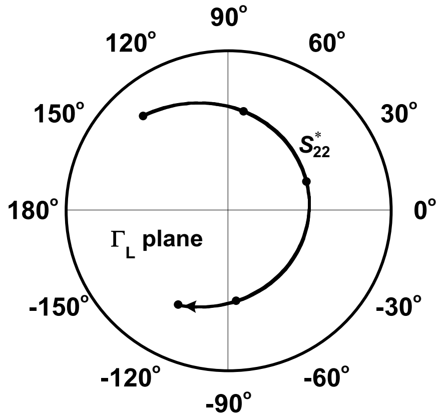

Fig. 4: S^*_{22} values are plotted on the Γ_L plane. The arrow indicates the direction in the increase of the argument ϕ.

The stub length for both input and output matching networks and the distance from the series stub to the port are plotted as a function of the argument ϕ as shown in Fig. 7 and Fig. 8, respectively. The stub lengths increase with the argument ϕ for both input and output matching networks. However, the variations of the distance between the stub and port for input and output matching networks are different and dissimilar to those of the stub lengths. The distances on the input side decrease with the argument ϕ while those on the output side increase then decrease with the argument ϕ with the peak observed at $\phi = 0^{\circ}$ approximately. Note that these results may be different for different sets of S parameters.

5. Conclusion

The unconditionally stable unilateral microwave transistor amplifier is designed in the CCITL system. It is observed that the transistor remains unilateral after the conversion of S parameters in a standard Z_0 system to those in the CCITL system. The effective gain factors are computed by optimizing for the maximum power gain therefore the source and load are terminated with the conjugate of S_{11} and S_{22}, respectively. All effective gain factors show variations with the argument ϕ but they are compensated for one another resulting in the constant unilateral transducer power gain $G_{TU,max}$. The design test is also optimized for the maximum power gain therefore choices of S^*_{11} and S^*_{22} are different for different argument ϕ. T-chart solutions for single-stub series tuners are employed to create input and output matching networks. It is found that stub lengths for both input and output matching networks increase with the argument ϕ. However the variations of the distance between the stub and port for input and output matching networks are different. The distances on the input side decrease with the argument ϕ while the trend is unclear on the output side. The advantage of using CCITLs for a unilateral microwave transistor amplifier will be further studied. Future work includes the design of potentially unstable unilateral amplifiers.

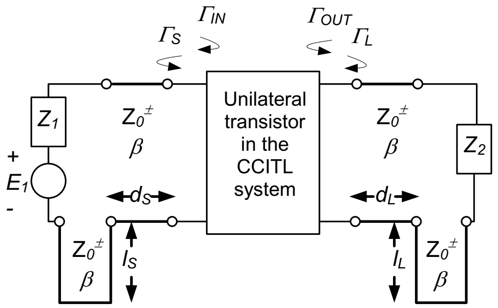

Fig. 5: A final schematic diagram of the unilateral amplifier using single-stub series stub tuners.

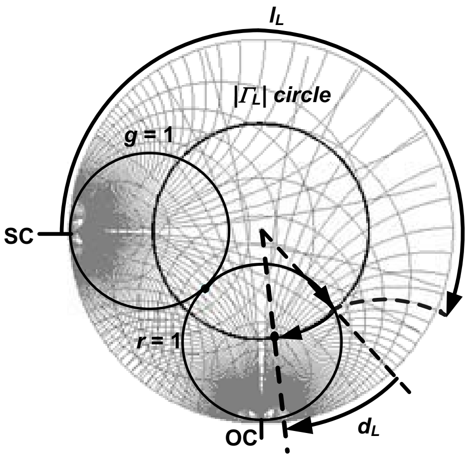

Fig. 6: T-chart solutions using single-stub series tuner for the output matching network at $\phi = 45^{\circ}$. Short- and open-circuited locations are represented by *sc* and *oc*, respectively.

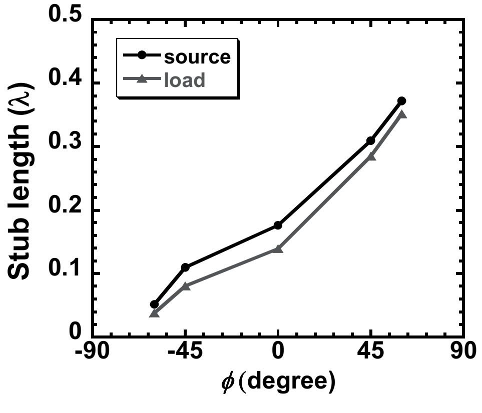

Fig. 7: The lengths of series stubs used for input (source) and output (load) matching networks are shown as a function of the argument ϕ.

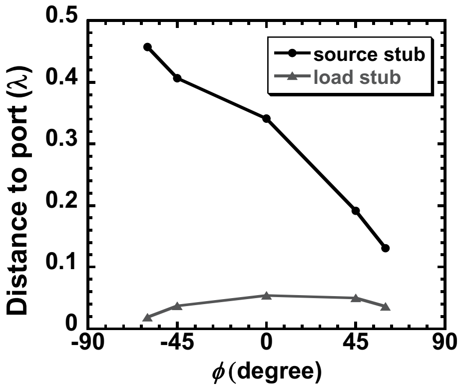

Fig. 8: The distances between stubs and ports calculated for input (source stub) and output (load stub) matching networks are shown as a function of the argument ϕ.

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