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# Improvement of a Class-C Transistor Power Amplifier by Second-Harmonic Tuning

SHAMSUR R. MAZUMDER, MEMBER, IEEE, ATAOLLAH AZIZI, STUDENT MEMBER, IEEE, AND FRED E. GARDIOL, SENIOR MEMBER, IEEE

*Abstract*—**Considerations for the effects of second-harmonic reactive terminations on the performances of a UHF class-C transistor power amplifier are presented. An experimental amplifier circuit design using coupled-TEM-bar transmission lines is described. This circuit can vary the fundamental and the second-harmonic impedance terminations of the amplifier independently. With this amplifier circuit, significant improvement in the performance characteristics of a class-C power amplifier were achieved by presenting proper values of second-harmonic reactive terminations, both at the input and the output of the transistor.**

## I. Introduction

IN POWER amplifiers, the transistor is operated as a nonlinear device under large-signal conditions. In certain situations (such as for class-C operation), the nonlinearity of the device generates significant amounts of harmonic components [1]. Furthermore, changes in the impedances presented to the transistor at the harmonic frequencies, while maintaining the same fundamental frequency impedances, result not only in changes in the relative values of the harmonic frequency components but also in different values of the fundamental frequency component. Thus for a good design method to accurately predict the performance characteristics of power amplifiers, one must take into account the significant effects of the source and the load terminating impedances at the harmonic frequencies [2], [7].

In the present work it is considered that the second harmonic is the most dominant of all harmonic components. This assumption may be justified by the fact that the transistor package tends to attenuate the third and higher harmonics considerably.

The purpose of this paper is to study the effects of second-harmonic reactive terminations on the performance characteristics of a class-C UHF transistor power amplifier. For this purpose, a coupled-TEM-bar circuit has been designed [3]–[5]. Two such circuits have been used, one at the input and the other at the output port of the transistor. These coupled-TEM-bar circuits can be adjusted to have an important property, i.e., that one can vary the fundamental and the second-harmonic impedances presented to the transistor terminals in a quite independent manner. This characteristic thus allows us to study the effects of varying the second-harmonic terminations on the performances of the amplifier. It is shown in this paper that a significant improvement in the performance characteristics (such as power output, dc-to-RF conversion efficiency and power gain) of a class-C transistor power amplifier can be achieved by proper choice of the second-harmonic reactive terminations of the amplifier.

In the following, the characteristics of the coupled-TEM-bar circuit are described with reference to the actual amplifier circuit. Experimental performances of the amplifier are also presented.

## II. Experimental Amplifier Circuit

The experimental amplifier circuit has been designed using two coupled-TEM-bar circuits [3]–[5], one at the

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The authors are with the Ecole Polytechnique Federale de Lausanne, Lausanne, Switzerland.

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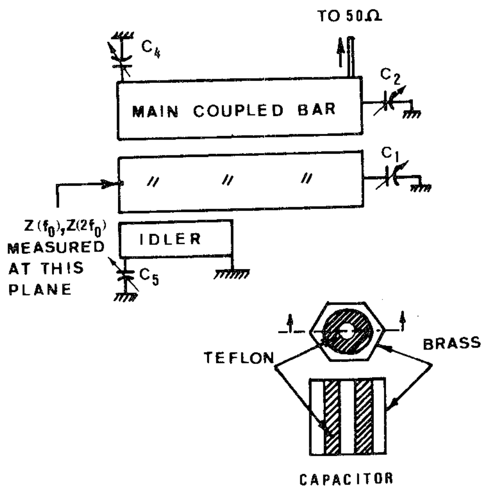



Fig. 1. Schematic of coupled-TEM-bar circuit.

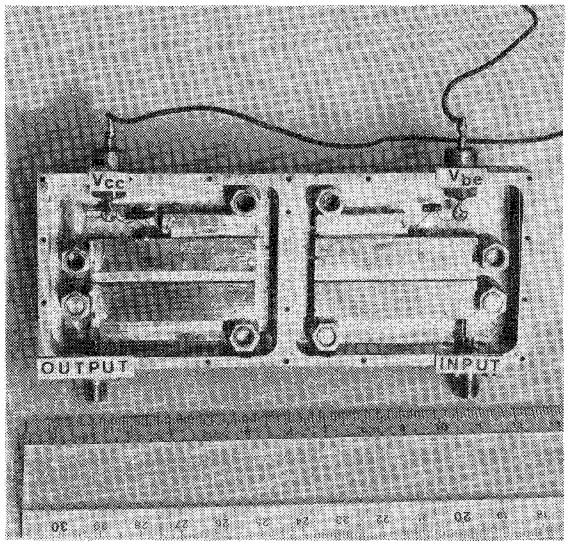



Fig. 2. Photograph of the coupled-TEM-bar amplifier circuit.

input and the other at the output of the transistor. A schematic of each of the coupled-TEM-bar circuits is shown in Fig. 1. This circuit consists of three coupled bars positioned between two ground planes operating in a TEM mode [4], [5]. Each of the two main coupled bars is approximately $\lambda/8$ long at the fundamental frequency ($f_0 \simeq 865$ MHz) of operation. These lines are capacitively loaded by the capacitors $C_1$, $C_2$, and $C_4$. A proper choice of these capacitors and the even- and odd-mode impedances of the main coupled bars make it possible to realize a wide range of impedance matching at $f_0$ while simultaneously presenting a reactive impedance at the second-harmonic frequency ($2f_0$), thus decoupling the second-harmonic signal from the 50-Ω load. This situation allows us to add a low-loss reactive "idler" [4], [5] (the third coupled bar) in order to vary the reactive impedance $Z(2f_0)$ at the second-harmonic frequency, without affecting the fundamental frequency impedance $Z(f_0)$. The third coupled bar is approximately $\lambda/8$ long at the second-harmonic frequency. This bar, in the present case, is shorted at one end and capacitively loaded by $C_5$ at the other end.

Thus in Fig. 1 the capacitors $C_1$, $C_2$, and $C_4$ are used first to establish the required fundamental frequency impedance $Z(f_0)$. Then, the second-harmonic reactive impedance $Z(2f_0)$ can be varied over a wide range by varying capacitor $C_5$.

The variable capacitors may be chosen from commercially available types. In the present design, however, they were made by using a small cylinder (threaded inside) of teflon which tightly fills a metallic (brass) cylinder. The value of the capacitor could be varied up to $\simeq 7$ pF by inserting a screw through the threaded teflon cylinder, as shown in Fig. 1.

A picture of the complete amplifier circuit (with the top cover removed) is shown in Fig. 2. The measurement of the impedances presented to the transistor terminals was accomplished by using a coaxial probe which was put in contact with the end of the main bar near the transistor terminal. The coaxial probe was passed through a hole (fitting the probe) drilled in the ground plane of the amplifier circuit. The overall dimensions of the amplifier circuit assembly are 12.5 cm × 5 cm × 1.8 cm.

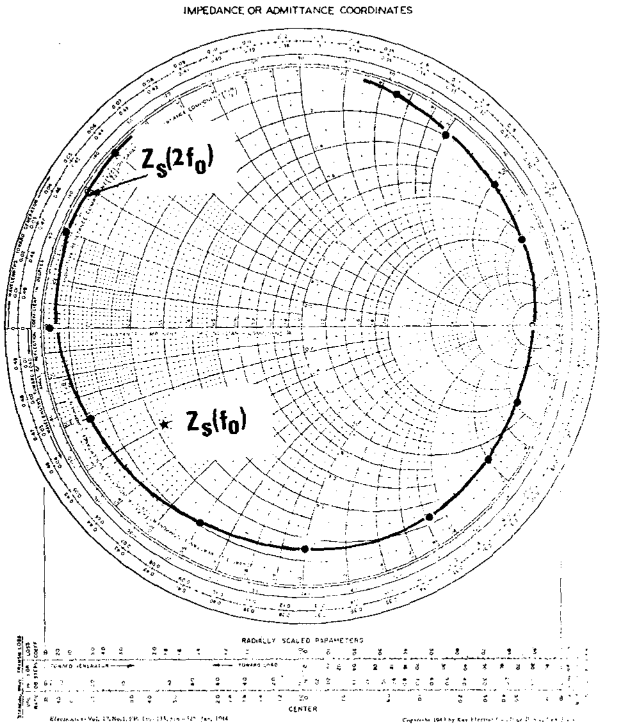
## III. Experimental Results

### A. Characteristics of the Coupled-Bar Circuits

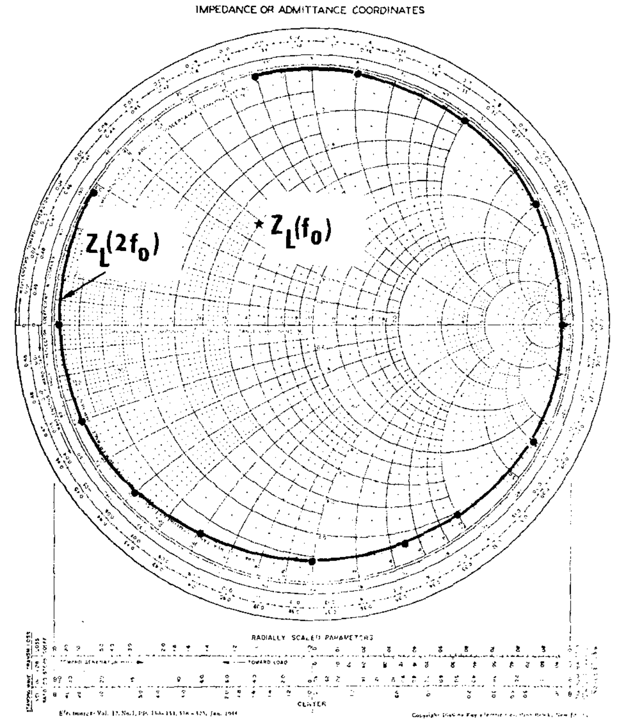
Characteristics of the two coupled-TEM-bar circuits are shown in Figs. 3(a) and (b). The fundamental frequency impedances, $Z_s(f_0)$ for the source and $Z_L(f_0)$ for the load circuit, were first adjusted by varying the capacitors ($C_1$, $C_2$, and $C_4$) loading the main coupled bars. Once the fundamental impedances are adjusted, the second-harmonic reactive impedances $Z_s(2f_0)$ and $Z_L(2f_0)$ can now be varied by the capacitors ($C_5$) loading the third coupled bar (idler) without changing the fundamental impedances $Z_s(f_0)$ and $Z_L(f_0)$, respectively, as seen from Fig. 3.

### B. Amplifier Characteristics

Experimental characteristics of a class-C amplifier ($V_{cc} = 12.5$ V, $V_{BE} = 0.0$ V) using a CTC transistor [type CTC D(1/2)-12(DHE)] at $f_0 \simeq 865$ MHz are presented in Fig. 4. To obtain these characteristics, first, the source and the load terminating impedances $Z_s(f_0)$ and $Z_L(f_0)$ at fundamental frequency were adjusted to obtain an "optimum" possible performance of the amplifier. Then, the second-harmonic reactive terminations $Z_s(2f_0)$ and $Z_L(2f_0)$ were varied to find the "best" and the "worst" possible performances of the amplifier. The performance characteristics of a power amplifier are appreciated in terms of power output ($P_{out}$), power gain ($G_p$) and dc-to-RF conversion efficiency ($\eta$). In Fig. 4(a), these results are presented, where the "solid" and the "broken" lines represent, respectively, the "best" and "worst" case of performances of the amplifier. Since in these two cases the fundamental impedances $Z_s(f_0)$ and $Z_L(f_0)$ are kept constant, the changes in the performances are only due to the second-harmonic reactive terminations of the amplifier. Fig. 4(b)

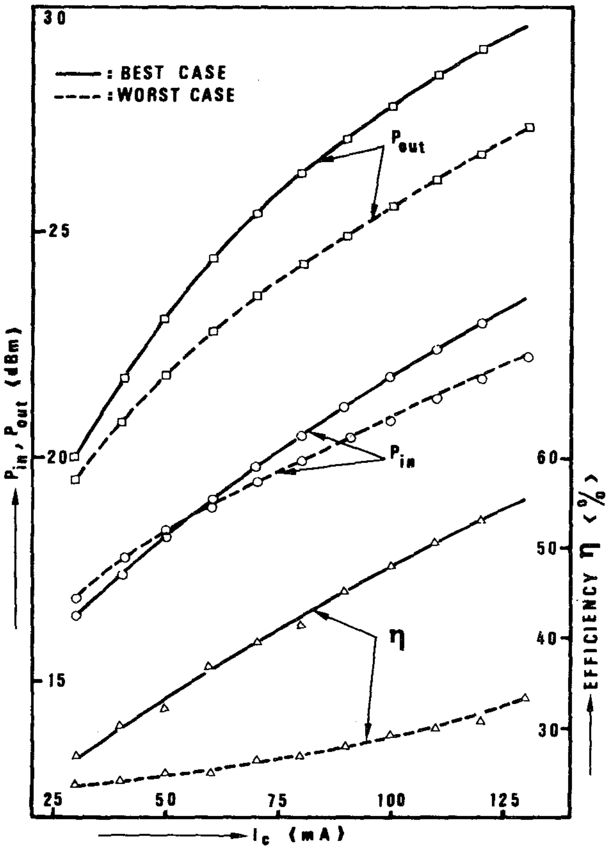



(a)

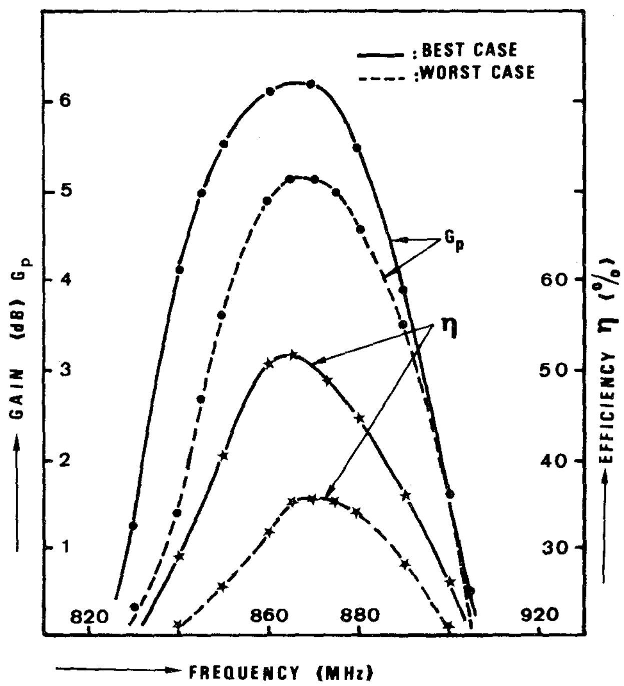



(b)

Fig. 3. (a) Range of second-harmonic reactive impedances (for the source termination) obtainable by tuning the third coupled bar in the amplifier circuit of Fig. 2. (b) Range of second-harmonic reactive impedances (for the load termination) obtainable by tuning the third coupled bar in the amplifier circuit of Fig. 2.




(a)




(b)

Fig. 4. (a) Experimental characteristics of the power amplifier. The "best" (solid lines) and the "worst" (broken lines) case were obtained by varying only the second-harmonic reactive terminations of the amplifier. (b) Frequency response of the amplifier for the "best" (solid lines) and the "worst" (broken lines) cases.

shows the frequency response of the amplifier corresponding to the "best" and the "worst" cases.

From the results given in Fig. 4(a), we observe that the performances of the amplifier can be quite significantly

TABLE I
SUMMARY OF AMPLIFIER PERFORMANCES

| PARAMETERS | BEST CASE | WORST CASE |
|---|---|---|
| Collector current ($I_c$) mA | 120 | 120 |
| Input power ($P_{in}$) mW | 200 | 150 |
| Output power ($P_{out}$) mW | 800 | 480 |
| dc to rf conversion efficiency η % <br> $\eta = \frac{P_{out}}{V_{cc} I_c} \times 100$ <br> $V_{cc} = 12.5$ V | 53.3 % | 32 % |
| Fundamental frequency $f_0$(MHz) | 865 | 865 |
| Source terminations at fundamental $Z_s(f_0)$ Ω | 11.5 - j15.0 | 11.5 - j15.0 |
| Source terminations at 2nd harmonic $Z_s(2f_0)$ Ω | 12.0 - j90.0 | 0.5 - j225.0 |
| Load terminations at fundamental $Z_L(f_0)$ (ohms) | 25.0 + j24.5 | 25.0 + j24.5 |
| Load terminations at second harmonic $Z_L(2f_0)$ (ohms) | 2.5 + j75.0 | 1.0 + j125.0 |

improved by tuning the second harmonic at the transistor terminals. In other words, it may be said that the performances of a class-C power amplifier can be significantly removed from the optimum case if the second-harmonic terminations are not properly chosen. Since, in high-efficiency power amplifiers, an increase in the dc-to-RF conversion efficiency can result in considerable saving in cost, size, and reliability [6], it appears that the effects of the second harmonic in power amplifiers may be of significant importance.

To better appreciate the significant effects of the second-harmonic tuning on the performances of the amplifier reported here, a summary of the results is presented in Table I.

A physical interpretation of the improvements in the performances of the amplifier may be obtained in terms of the voltage and current waveforms at the transistor terminals. The tuning of the second harmonic may be viewed as "shaping" these voltage and current waveforms to minimize the voltage across the device when current flows through it and/or to minimize the current through the device when voltage exists across it [6].

## IV. CONCLUSION

Significant effects of second-harmonic reactive terminations on the performances of a UHF class-C transistor power amplifier are presented. The amplifier circuit has been fabricated by using coupled-TEM-bar circuits. These 3-bar coupled-bar circuits enable one to present, quite independently, the fundamental impedances and the second-harmonic reactive terminations at the input and the output port of the transistor. It has been shown that the performances of a transistor power amplifier can be significantly improved by properly tuning the second harmonic. These results also indicate that, if attention is not paid to the second-harmonic terminations, the amplifier performances may be quite significantly less than optimum ones.

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