Push–Pull Power Amplifiers in the X band

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Abstract

Two types of class C push–pull power amplifiers for the X band are newly devised. In these amplifiers, tuning type amplifiers are constructed using $TE_{01\delta}$ mode dielectric resonators, and phase inverting circuits which are necessary at the input and output sides of the push–pull power amplifiers are also constructed using the $TE_{01\delta}$ mode dielectric resonators.

The experiment was performed for the two amplifiers. The operating frequency of the first amplifier was 12.4 GHz, the output power was 37.2 dBm, and the power added efficiency was 75 %. For the second amplifier, the operating frequency was 11.2 GHz, the output power was 46 dBm, and the power added efficiency of 77 % was attained.

1) Introduction

Recently, for portable telephone and mobile communication, a power amplifier whose DC power comsumption is as low as possible is demanded. Moreover, in the power amplifier for the transmitter loaded on the communication satellite, a large amount of heat is produced from semiconductor devices, and hence a power amplifier with high power added efficiency is indispensable. Such amplifiers have already been proposed in Refs. [1]–[4]. These amplifiers employ a trapezoidal or rectangular waveform to obtain high power added efficiency, and require wide–band characteristics to produce these waveforms.

The author constructed a tuning type amplifier by using $TE_{01\delta}$ mode dielectric resonators in a conventional class C power amplifier. In Ref. [1], it was stated that the power added efficiency becomes large if we make the operating angle θ_1 of the input wave small. When we set the operating angle θ_1 at the final stage of this amplifier to 50°, the power added efficiency was almost the same as those of the high efficiency power amplifiers described in Refs. [1]–[4]. In this paper, two types of class C push–pull power amplifiers for the X band are proposed. The phase inverters used in the input and output sides of these amplifiers are formed by $TE_{01\delta}$ mode dielectric resonators.

2. Tuning Type Push–Pull Power Amplifiers

2.1 Circuit Configuration

In Refs. [1]–[4], the trapezoidal waveform with operating angle $\theta_1 = 74°$ and the rectangular waveform with $\theta_1 = 30°$ or $60°$ were employed to make the power added efficiency large. To amplify these waves and reproduce them at the output of the amplifier, it should have wide–band characteristics. When we operate the high efficiency amplifier at 10 GHz using the trapezoidal waveform, we cannot reproduce this waveform unless we compensate the frequency characteristics from about 9 GHz to 35 GHz, because the trapezoidal waveform is synthesized by the fundamental and the 3rd harmonics. As seen from this example, we cannot obtain large power added efficiency without an amplifier which has wide–band frequency characteristics. In the millimeter wave region, extremely wide–band characteristics are required. Considering these points, the author devised a tuning type push–pull power amplifier which can be constructed by a simple circuit having not so wide–band characteristics. In this amplifier, we can obtain the power added efficiency which is almost the same as that of the high efficiency power amplifier. To obtain large power added efficiency, we set the operating angle θ_1 of the waveform supplied to the final–stage amplifier to 50°, and employed a conventional class C power amplifier. By using the $TE_{01\delta}$ mode dielectric resonator in this amplifier, we constructed the tuning type amplifier, and the phase inverters which are necessary at the input and

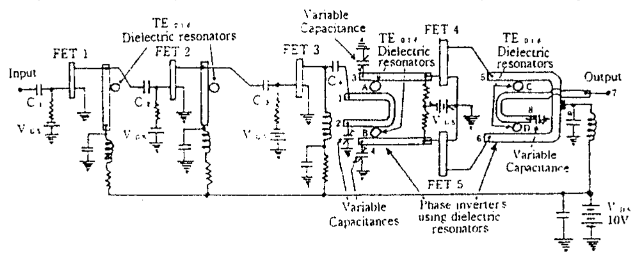

Fig. 1 Circuit system of the class C push–pull power amplifier.

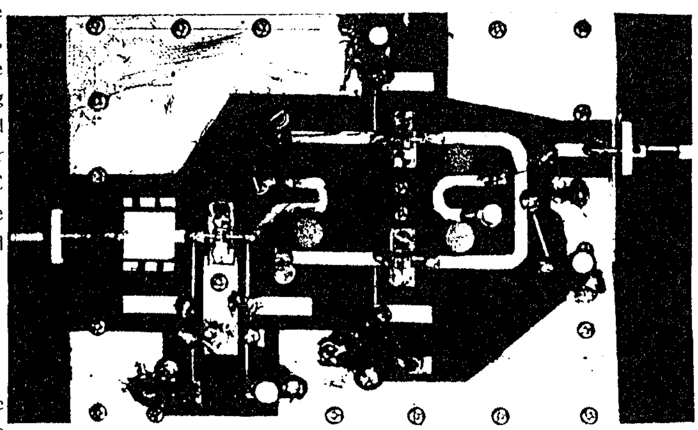

Fig. 2 Photograph of the power amplifier shown in Fig. 1.

output sides of the push–pull power amplifier were also constructed by the $TE_{01\delta}$ mode dielectric resonators. Two types of push–pull power amplifiers were devised and the operation of these circuits is described in the following.

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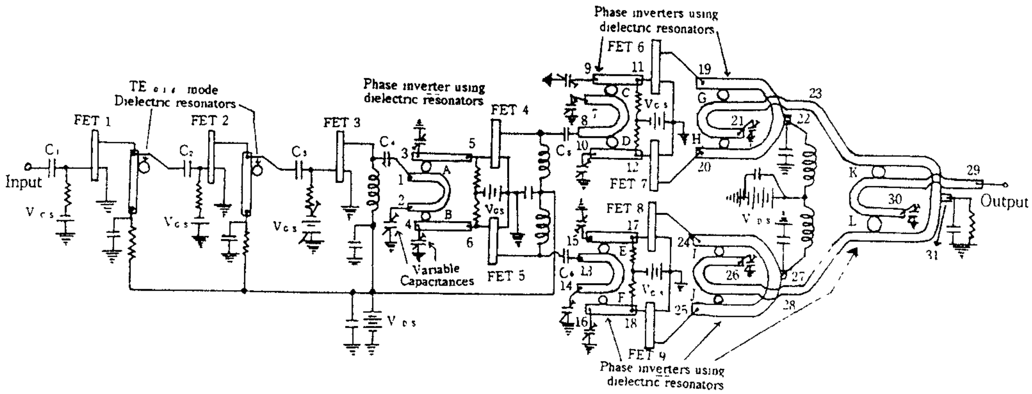

Fig. 4 Circuit system of the class C push-pull power amplifier.

Figure 1 shows the circuit configuration of the first type of class C push-pull power amplifier, and Fig. 2 is a photograph of this amplifier. As shown in Fig. 1, the TE $_{01\delta}$ mode dielectric resonator is employed and, as a result, the amplifier is tuning type. FET1 is a pre-amplifier and the gate bias voltage V_{GS} was set to a value for which the FET1 operates as a class A amplifier. FET2 also operates as a class A amplifier. We see that transmission lines are connected between the drain and drain supply voltage V_{DS} of FET 1 and FET 2. If we place the TE $_{01\delta}$ mode dielectric resonators close to the transmission lines, a tuning type amplifier is obtained. The resonance frequency of the resonators is 12.4 GHz. The output waveform which is amplified by FET1 is supplied to the gate of FET2 through the coupling capacitance C_2, and it is further amplified by FET2. The output from FET2 is supplied to the gate of FET3 through the coupling capacitance C_3 for power amplification. The output voltage appearing at the drain side of FET3 is fed to the terminal 1 of the U-shaped transmission line through the capacitance C_4.

As shown in Fig. 1, we place the TE $_{01\delta}$ mode dielectric resonator A between the U-shaped transmission line and the transmission line which is connected to the gate of FET4. The resonance frequency of this resonator is 12.4 GHz, which is the same as that of the resonators placed in the drain sides of FET1 and FET2. Since the portion where the dielectric resonator A is placed works as a band-pass filter, the waveform with phase angle 0° is supplied to the gate of FET4. Moreover, to form a phase inverter, we place another dielectric resonator B at a position which is about $\lambda_g/2$ apart from resonator A. Resonator B is placed between the U-shaped transmission line and the transmission line which

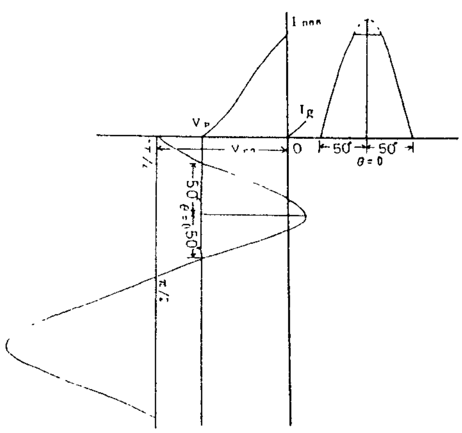

Fig. 3 Bias voltage for obtaining the synthesized voltage whose operating angle is 50°

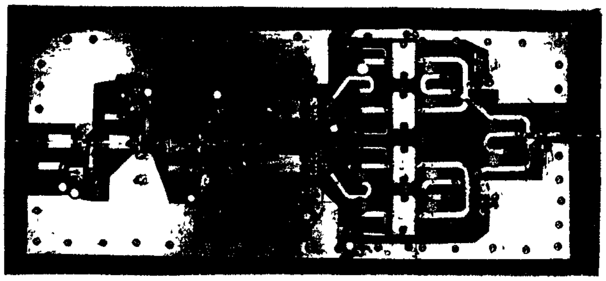

Fig. 5 Photograph of the power amplifier shown in Fig. 4

is connected to the gate of FET5. The wave with the phase angle 180° is supplied to the gate of FET5. By connecting variable capacitances between the terminals 2, 3, and 4 of the U-shaped transmission line and the earth, we obtain the impedance matching.

The waves with the phase angles 0° and 180° are power amplified by FET4 and FET5. As shown in Fig. 3, the bias voltage V_{GS} supplied to the gates of these FETs was so chosen that the operating angle θ_1 becomes 50°. By making the operating angle small, we can obtain large power added efficiency as described in Ref. [1]. In the output wave which was amplified by FET4 and FET5, the higher-order components are contained. The phase converter consisting of the dielectric resonators is placed at the output side, and it yields the fundamental wave with frequency f_0. In the following, detailed operation of the phase inverter is descirbed.

The output at the drains of FET4 and FET5 contains the higher-order modes. This output supplies the two waves whose phase angles are 0° and 180° to the terminals 5 and 6 of a small U-shaped transmission line, which is located inside the larger U-shaped line. Between these transmission lines, two dielectric resonators C and D are placed. The distance between the resonators C and D is about $\lambda_g/2$. Since the portion where two dielectric resonators C and D are placed works as a band-pass filter, the fundamental component with frequency f_0 is extracted. At the terminal 7, the two output waves with phase angles 0° and 180° are combined. By connecting a variable capacitance between terminal 8 of the small U-shaped transmission line and the earth, we obtain the impedance matching. We supply the DC voltage V_{DS} to the drains of FET4 and FET5 through terminal 9 of the large U-shaped transmission line. By setting this terminal 9, which is similar to a midpoint tap of a phase inverter formed by a lumped circuit, the even-order harmonics are cancelled out.

Figure 4 shows the circuit structure of the second type of a push-pull power amplifier and its photograph is shown in Fig. 5. As we see in Fig. 4, a transmission line is connected between the drains of FET 1, 2 and the drain source V_{DS}. By placing the $TE_{01\delta}$ mode dielectric resonator near the transmission line, we have a tuning type amplifier. The output wave amplified by FET1 is supplied to the gate of FET2 through a coupling capacitance C_2. The output from FET1 is further amplified by FET2 and, through the capacitance C_3, is supplied to the gate of FET3 for amplification. The output wave obtained at the drain side of FET3 is supplied to the terminal 1 of U-shaped transmission line through the capacitance C_4. We place $TE_{01\delta}$ mode dielectric resonator A between the U-shaped transmission line and the transmission line that is connected to the gate of FET4. The resonance frequency f_0 of resonator A is the same as those of the resonators which are employed at the drain sides of FET1 and FET2. The portion where the dielectric resonator is loaded works as a band-pass filter, and the output wave with the phase angle 0° is supplied to the gate of FET4. We place another dielectric resonator B at a position which is about $\lambda_g/2$ apart from resonator A. The portion where the dielectric resonator B is loaded also works as a band-pass filter, and the output wave with the phase angle 180° is supplied to the gate of FET5.

The output wave at the drain side of FET4 is supplied to the terminal 8 of U-shaped transmission line through the capacitance C_5. Since the distance between the two dielectric resonators C and D is set to about $\lambda_g/2$, the output wave with the phase angle 0° is supplied to the gate of FET6, and the output wave with the phase angle 180° is supplied to the gate of FET7. By connecting variable capacitances between terminals 7, 9, 10 of the phase inverter and the earth, we obtain the impedance matching.

The output wave at the drain side of FET5 is supplied to the terminal 13 of U-shaped transmission line through the capacitance C_6. The distance between the two dielectric resonators E and F is set to about $\lambda_g/2$. The output wave with the phase angle 0° is supplied to the gate of FET8, and the output wave with the phase angle 180° is supplied to the gate of FET9. Variable capacitances are connected between terminals 14, 15, 16 of the phase inverter and the earth to obtain the impedance matching.

The gate bias voltages V_{GS} of FET 6 ~ 9 for power amplification were set to the values for which the operating angles of the waveforms become 50°. The output waves amplified by FET 6 ~ 9 contain the higher-order components. By using the phase inverter which consists of the $TE_{01\delta}$ mode dielectric resonators, we pick up the fundamental waves with f_0 and combine them.

The output waves arising at the drain sides of FET6 and FET7 in the push-pull power amplifier are supplied to the terminals 19 and 20, respectively, of the large U-shaped trasmission line of the phase inverter. We placed the $TE_{01\delta}$ mode dielectric resonators G and H, which are separated by about $\lambda_g/2$, between the large and small U-shaped transmission lines. With this setting, the phase angle of the output wave at the drain side of FET6 becomes 0° and that of the output wave at the drain side of FET7 becomes 180°. The two output waves having different phase angles are combined at the output terminal 23 of the small U-shaped transmission line. The synthesized output wave is transmitted to the phase inverter of the final stage.

The output waves arising at the drain sides of FET8 and FET9 in the push-pull power amplifier are supplied to the terminals 24 and 25, respectively, of the large U-shaped trasmission line of the phase inverter. We placed the $TE_{01\delta}$ mode dielectric resonators I and J with their separation being about $\lambda_g/2$ between the large and small U-shaped transmission lines. As a result, the phase angle of the output wave at the drain side of FET8 becomes 0° and that of the output wave at the drain side of FET9 becomes 180°. The two output waves having different phase angles are combined at the output terminal 28 of the small U-shaped transmission line. The synthesized output wave is transmitted to the phase inverter of the final stage.

Variable capacitances are connected between the terminals 21 and 26 of two small U-shaped transmission lines and the earth to obtain the impedance matching. We supply the DC voltage V_{DS} to the drains of FET6 ~ 9 through the midpoint terminals 22 and 27 of the large U-shaped transmission line. The outputs from two push-pull power amplifiers are supplied to the terminals 23 and 28 of large U-shaped transmission line of the phase inverter at the final stage. Two outputs with phase angels 0° and 180° are combined through the $TE_{01\delta}$ mode dielectric resonators K and L which are placed between the small and large U-shaped transmission lines. The combined output is picked up from the terminal 29. Between the midpoint 31 of large U-shaped transmission line and the earth, terminal resistance and capacitance are connected in parallel.

3. Experimental Results

The experiment was performed for the two push-pull power amplifiers. The frequency characterisitcs of the first amplifier are shown in Fig. 6. The center frequency was 12.4 GHz, and we obtained the maximum power of 37.2 dBm, and the power added efficiency of 75 %. The bandwidth of the amplifier was 50 MHz. The results for the second amplifier are shown in Fig. 7, with the center frequency of 11.2 GHz. The maximum output power and the power added efficiency were 44.1 dBm, and 77 %, respectively. The bandwidth was 50 MHz.

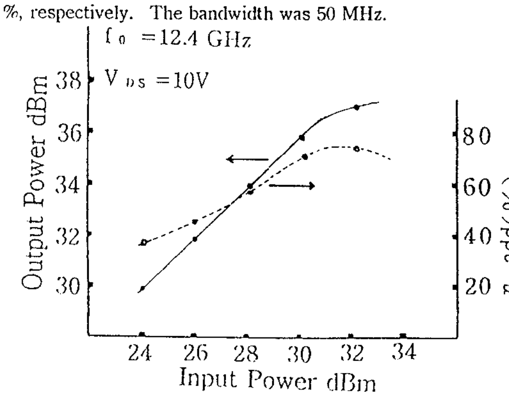

Fig. 6 Dependence of the output power and power added efficiency on the input power for the amplifier of Fig. 1.

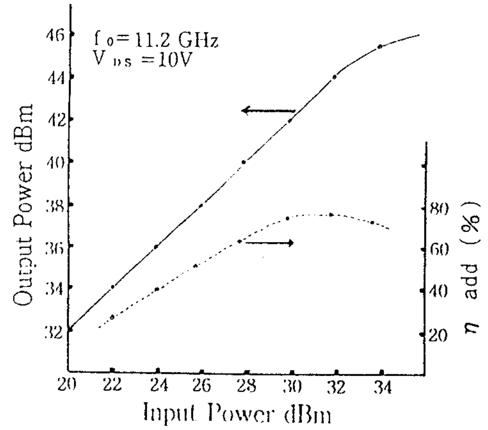

Fig. 7 Dependence of the output power and power added efficiency on the input power for the amplifier of Fig. 4.

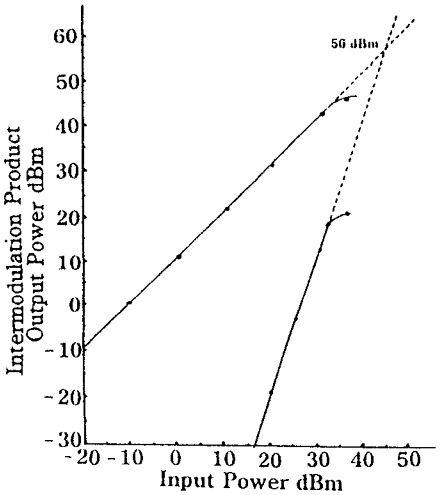

Fig. 8 Output power and third order intermodulation production versus input power at center frequency (f_0 = 11.2 GHz, f_1 = 11.205 GHz)

By using tuning type amplifiers and the phase inverters which were constructed by $TE_{01\delta}$ mode dielectric resonators, we obtained ideal frequency characteristics for the two push-pull power amplifiers.

Figure 8 shows the measured results of the input-output characteristics and third order intermodulation distortion of the power amplifier. The measurement was done with a spectrum analyzer by injecting into the amplifier the fundamental signal at 11.2 GHz and the signal with the same level but at frequency shifted by 5 MHz. The intercept point was 56 dBm.

4. Conclusion

In this paper, two newly devised push-pull power amplifiers in the X band have been described and their performances were demonstrated. An important point is that we constructed tuning type amplifiers and phase inverters by using $TE_{01\delta}$ mode dielectric resonators. By employing low power FETs and the resonators with large unloaded Q-factor, we can obtain large amplifier gain and the power added efficiency which is close to that of a high efficiency amplifier. If we use the above mentioned inverters, it is possible to obtain the amplifiers for millimeter wave region that have large output power and large power added efficiency.

5. References

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