UHF high-power low-distortion transistor amplifier with high-dielectric (ε_r=39) substrate

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Abstract

A hybrid-integrated UHF power amplifier has been designed and fabricated on high-dielectric (ε_r=39) substrate. The amplifier was developed to replace TWTs in television transposers and provides a rated output peak power of 32W with low-distortion characteristic over the 650∿770 MHz frequency range.

Introduction

At microwave frequency, high-dielectric ceramics is mostly applied to dielectric resonators. Microstrip transmission-line parameters on high-dielectric substrate are described in [1]. Practical application, however, to use it for microwave integrated circuitry, has not been reported so far.

Main features of a microstrip on high-dielectric substrate are its low impedance and short wavelength characteristics. These characteristics are particularly attractive for UHF power amplifiers [2][3], because high-frequency power transistors have, in general, very low input and output impedances and free space wavelength of UHF signal is as long as several scores of centimeters.

In addition, by employing high-dielectric substrate, UHF distributed-element circuits can be realized easily, although conventional UHF power amplifiers are constructed by soldering discrete lumped elements to conductor patterns on alumina or teflon-glass substrate. As a result, the discrete elements can be eliminated and low-cost, high-reliable and small size UHF power amplifiers are obtained.

This paper will present design techniques for and results obtained from a UHF high-power low-distortion transistor amplifier integrated on high-dielectric substrate. The amplifier has been developed for replacing TWTs in television transposers.

Properties of microstrip on high-dielectric substrate

High-dielectric material used here as a microstrip substrate is BaO-TiO_2-system ceramics, which is newly developed in Central Research Laboratories, NEC [2]. This ceramics (NED-39) has a relative dielectric constant (ε_r) of 39 and loss tangent (tan δ) of below 2×10^{-4}. Temperature dependency of ε_r is -20×10^{-6}/°C, which compensates for thermal expansion of the ceramics, so that the temperature coefficient of resonant frequency would be less than 2×10^{-6}/°C. This temperature stable property is especially suitable for high-power circuits, because thermal dependence of circuit parameters becomes a serious drawback.

Measured and calculated characteristic impedance and wavelength of the microstrip on the 0.5mm thick substrate are shown in Fig.1. It would be clear from the figure that both characteristics are about 1/2 to 1/4 times smaller than those in conventional alumina or teflon-glass substrate. This makes it easy to realize low impedance circuits and possible to reduce circuit size. For example, necessary line width and length of a quarter wavelength 10Ω line at 700 MHz are 2.6mm and 19.0mm, respectively.

Transmission loss is also measured and calculated. The result shows conductor loss is highly dominant and that dielectric loss of the substrate has a negligible effect. The strip conductor is printed by thick film technique with Au paste. Printed conductor thickness is about 10μ, which is several times thicker than skin depth. Measured Qo of 1mm width microstrip is about 80 at 700 MHz. This value is nearly equal to that for a thin film conductor.

For impedance matching circuits, low-pass LC ladder-type circuits are often employed. Since the transistor impedance is very low, high capacitance is required for the parallel capacitor. In conventional circuits, a multilayer ceramic chip capacitor has been mainly used for this purpose. The chip capacitor, however, has unavoidable self-resonance, whose frequency is below 1 GHz for higher than 30pF capacitance. In marked contrast, in the high-dielectric substrate circuit, high capacitance can be simply obtained by forming a large electroconductive pattern on the substrate. The capacitor electrode is extended to microstrip conductor continuously on the substrate without any connection leads or terminals for soldering. This causes an increase in circuit reliability and reduces circuit loss. Besides, capacitance value can easily be adjusted by bonding or cutting out a small section of capacitor electrode. Figure 2 shows measured reactance variations of a multilayer ceramic chip capacitor and the present single-layer capacitor, which is realized by parallel connection of two 30pF capacitors. The electrode size for a 30pF capacitor is 4.7Wx7.0L (mm). The self-resonant frequency, where reactance becomes zero, is raised up to above 1 GHz for the present capacitor.

In high-dielectric substrate microstrip, electric field is concentrated in the substrate. Therefore, radiation from discontinuities is relatively small and no higher-mode transmission or spurious resonance of the shielding case can be observed.

Circuit constructions

The amplifier schematic construction and set-up view are shownin Fig.3. All transistors in the amplifier are Si-bipolar transistors whose maximum rated output power is 30W for class-C operation. Third-order intermodulation distortion (IMD_3) is one of the most serious problems in power amplifiers. In order to achieve low IMD_3, transistors are usually in class-A operation. In the present amplifier for television transposers, however, low IMD_3 is required at only specified output power level. Therefore, transistors in the last three stages are operated in class-AB, considering efficiency and handling power capability.

A typical example of load-pull output impedance for the transistor is shown in Fig.4, which corresponds to the last stage. Similar data for various frequency and power conditions have been widely measured. Input impedance of the transistor lies around 2∿5Ω, which is lower than output impedance. Note that the objective impedance region, where IMD_3 is below -56dB, is very narrow. Therefore, the design of matching circuits has been performed by CAD program.

Tandem connection of two parallel-line 8.3dB couplers is employed as a hybrid power divider or combiner. The couplers are designed with 25Ω normalizing impedance, which makes circuit design easier and also reduces circuit loss.

Overall amplifier size is 75Wx165Lx16H (mm).

High-power low-distortion amplifier characteristics

Figure 5 shows the amplifier performance when the output peak power of synchronizing video-signal pulse is 32W, which corresponds to CW power of about 20W for red color. The color signal consists of video, audio and subcarrier components. Power levels of the components for each color, according to the NTSC system, are tabulated in the figure. The plotted IMD_3 values represent the 920 KHz color beat measured down from peak power of the synchronizing pulse.

Figure 6 shows output power response for the total input power of the color signals, together with the worst IMD_3 of the three color signals. Although the power response curve is not linear, due to the class-AB operation, a low IMD_3 characteristic is obtained at around 42dBm rated total output power.

More than 36dB power gain, more than 17% power added efficiency and less than -56dB IMD_3 have been achieved over the 650∿770 MHz frequency range. By compensating bias current with temperature sensitive base bias resistor, almost the same characteristics can be obtained over the -10∿45°C temperature range.

A number of above-mentioned amplifiers are combined in parallel by Wilkinson-type power combiners to provide a rated output peak power of 50W, 100W and 300W. The combined amplifier enables to replace TWTs in UHF television transposers.

Conclusion

High-dielectric substrate has been found to be very suitable for an integrated UHF power amplifier, on account of easy low impedance circuit realization and possible reduction in circuit size. By using high-dielectric substrate, a low-cost, high-reliable and small size UHF power amplifier for television transposers has been successfully developed.

Acknowledgment

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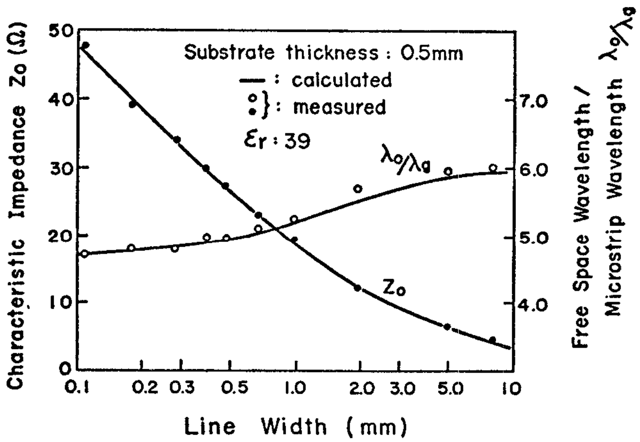


Fig.1 Transmission-line parameters vs. line width characteristic for a high-dielectric substrate microstrip.

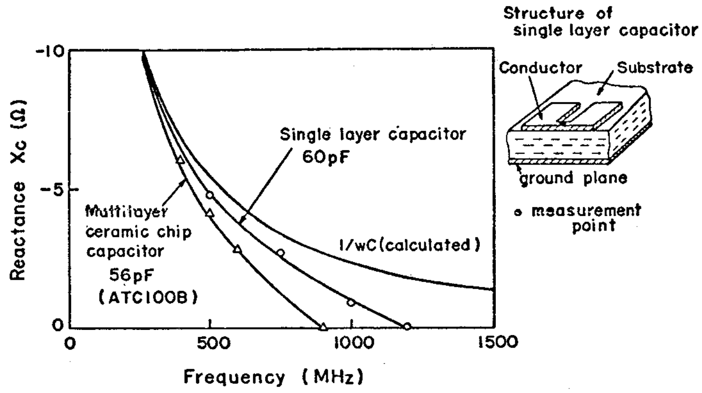
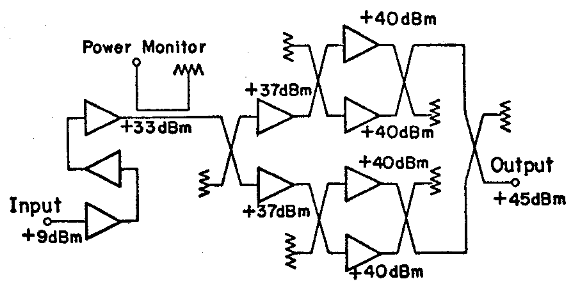
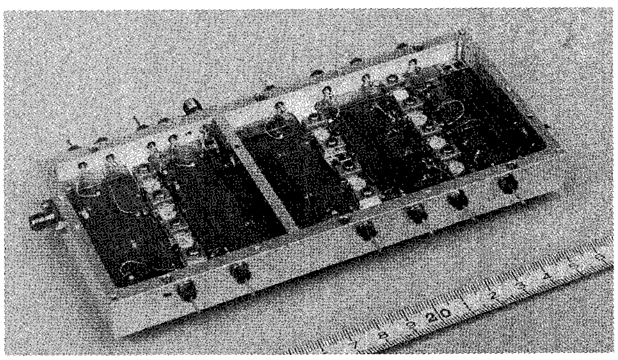


Fig.2 Parallel capacitor reactance component vs. frequency characteristics.



(a) Schematic for amplifier circuit.



(b) Interior amplifier view.

Fig.3 Amplifier construction.

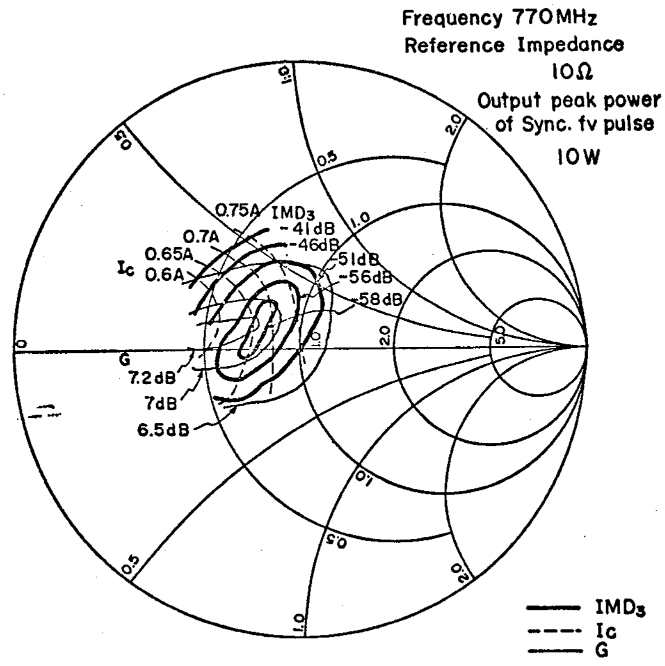


Fig.4 Load-pull output impedance contours of constant third-order intermodulation distortion product (IMD3), constant gain (G) and constant collector current (Ic).

Peak power of Sync. fv pulse = 0dB

	Red	Green	Yellow
fv	-4.67	-6.82	-9.87dB
fA	-6.0	-6.0	-6.0
fs	-17.0	-17.58	-20.16

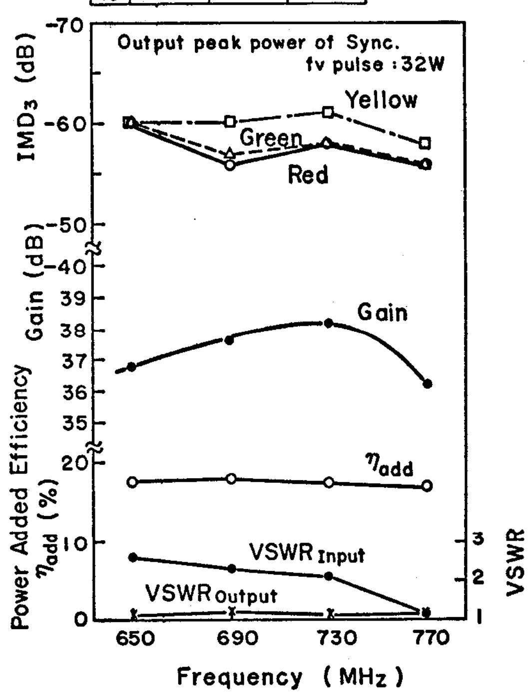


Fig.5 Amplifier performance.

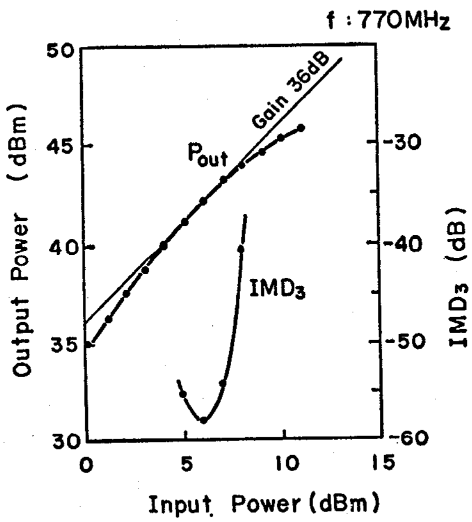


Fig.6 Output power vs. input power and third-order intermodulation distortion product (IMD3).