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Miniature Beryllia Circuits for Ku-Band Power Amplifiers

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ABSTRACT

Ku-band power amplifiers have been developed using miniature circuits fabricated on glazed beryllium oxide. This new technology is particularly well suited for miniature, light-weight, high performance GaAs power amplifiers. Experimental results illustrate the basic viability of this approach: the performances obtained from 1/2-W and 1-W amplifiers operating at Ku-band are already better than those obtained by more standard technologies. A cascode amplifier, also built on BeO has shown exceptionally broadband performance.

A new technology for fabricating miniature circuits on glazed beryllium oxide has been developed.[1] It combines the advantages of the monolithic approach - very small size, light weight and batch fabrication, with the advantage of the hybrid approach - flexibility of using separately attached active devices. Beryllium oxide (BeO) substrates, that feature excellent heat conductivity and low rf loss, are used to support a combination of distributed and lumped circuit elements. The BeO substrates, that are rough even when polished, are selectively glazed to provide smooth surfaces for the definition of high Q lumped-element components, such as inductors and thin-film capacitors. The active devices, GaAs power FETs in pellet form, are flip-chip mounted on unglazed sections of the BeO surface. A low parasitic ground connection for the FET source contacts is provided by a metal septum that is fabricated as an integral part of the BeO substrate.

Ku-Band Power Amplifiers

Figure 1 is a photograph of four Ku-band amplifiers batch fabricated on a strip 0.2" x 1.0" x 0.015" in size. Clearly visible is the metal septum embedded at the center of the substrate. The circuit at the far right is completed with a GaAs FET pellet mounted on the unglazed section over the ground septum.

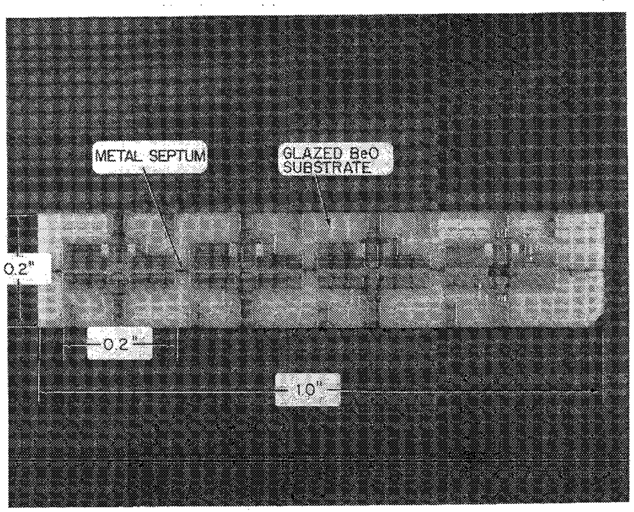

Fig. 1. Strip of Ku-band power amplifiers

Figure 2 is a close-up of the Ku-band amplifier. The wide H-shaped pattern at the center is the ground metallization. The FET pellet is flip-chip mounted using a high-temperature solder. The input tuning circuit, at the gate, is formed by a short section of line and by pairs of 0.6 pF tuning capacitors connected in series, in a symmetrical configuration. For ease of experimentation these capacitors are presently interconnected by short bond wires that eventually will be replaced by airbridges. By selecting different capacitors, the center of the operating band can be tuned over approximately 1 GHz. The circuit includes inductive lines for biasing and 7 pF capacitors for DC block and RF bypass. Part of the output tuning circuit is an interdigitated structure which allows simple realization of lower value (0.15 pF) high Q capacitors.

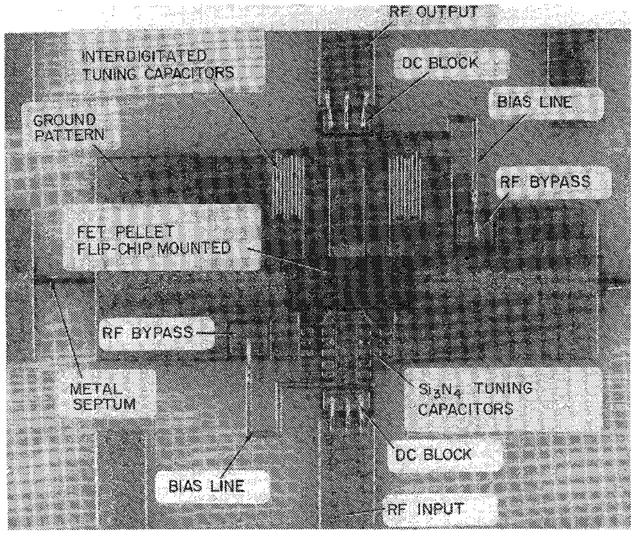

Fig. 2. Photograph of 1/2 W Ku-band amplifier

The power performance of one of these circuits is shown in Fig. 3. The FET is an RCA 2-cell structure having a total gate width of 1200 μm and a nominal output power of 1/2 W. The device features polyimide passivation for protection of the active channel during the soldering operation. At 16.25 GHz, the output power was 711 mW with a gain of 3.0 dB and an efficiency of 18.7%. The power-added efficiency peaked at 19.6 with an output power of 650 mW. The small signal gain was 4.8 dB with a 1 dB bandwidth of 1 GHz. This power performance is more than 1 dB higher than what can be obtained from similar devices mounted on copper carriers.

Figure 4 is a photograph of an amplifier developed for 1W of output power. The FET pellet - flip-chip bonded at the center of the substrate - is an RCA device featuring a 4-cell structure and a total gate width of 2400 μm. The input and output tuning of the FET is achieved by short inductive lines and by Si_3N_4 capacitors. Of significance in this design is the presence of stubs connected to the septum near the FET. Their effect is to reduce the impedance of the FET source connection to ground, thereby increasing the gain and the output power.

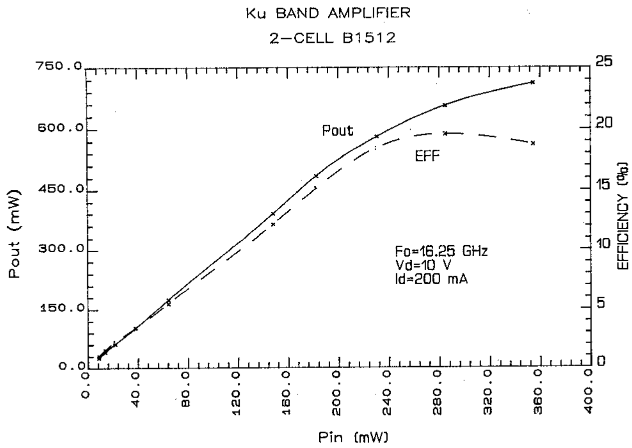

Fig. 3. Power performance of the 1/2 W amplifier

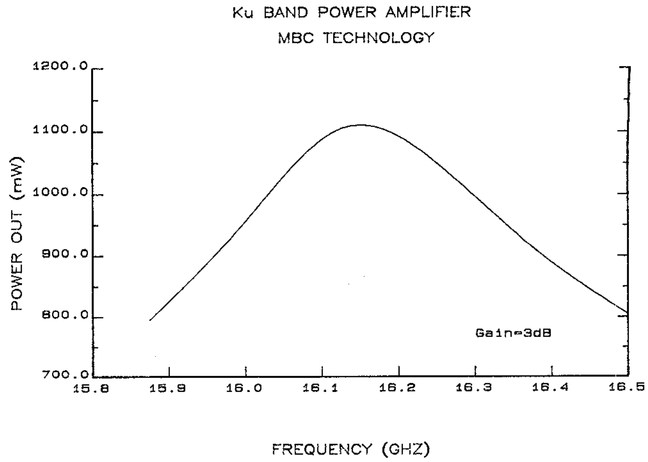

Fig. 5. Output power at 3dB gain for the 1-W amplifier

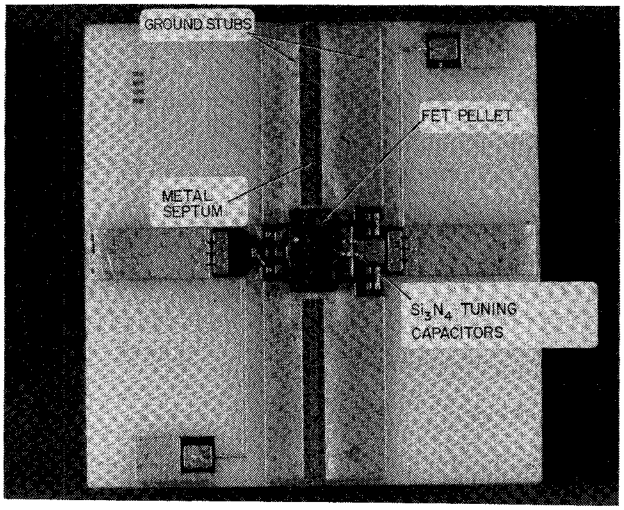

Fig. 4. Photograph of 1-W Ku-band Amplifier

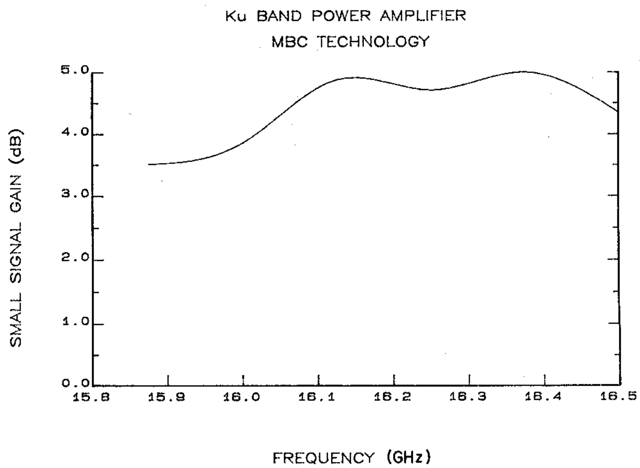

Fig. 6. Small-signal gain for the 1-W amplifier

Figure 5 shows the output power at 3 dB gain plotted as a function of frequency. The power exceeded 1 W over a bandwidth of 300 MHz. The power added efficiency was approximately 14%. The small-signal gain as a function of frequency is shown in Fig. 6. A minimum gain of 4.5 dB was achieved over a bandwidth of 400 MHz. Here also, as in the 1/2 W design, the power performance is more than 1 dB higher than that obtainable from standard technology with FETs mounted on copper carriers and tuned by distributed or lumped circuitry. This improvement is attributed to the lower impedance of the source connection realizable using the MBC technology.

Cascode Amplifier

Another circuit realized with MBC technology was a cascode amplifier. The cascode configuration required two FETs connected in series. Regular power FETs, however, are configured with cell connected in parallel, as shown in Fig. 7a. For realizing the cascode amplifier a series configuration was obtained, without any change in the FET layout, by reversing the bias of the first FET cell as shown in Fig. 7b. The cascode circuit (Fig. 7c) - obtained by rf grounding gate G_2 - has the interesting features of high gain and broadband. An analysis of the circuit shows that the first device is loaded at the output by the low impedance of the source to gate of the second device and offers broadband operation because the loading reduces the effect of the output capacitance. The second device operates in common gate and has a gain increasing with frequency (within a certain range) because the source to drain capacitance induces a positive feedback. The result is a circuit which has remarkable broadband capabilities. The circuit whose layout is depicted in Fig. 7d was constructed using a regular 2-cell FET pellet of the same type as the one used for the 1/2 W amplifier.

The performance of the amplifier is shown in Fig. 8. The small signal gain is approximately 9 dB from 2 to 12 GHz without any external tuning. An excellent performance, indeed, for such a simple circuit. The power performance, obtained with the aid of some external tuning, is also tabulated in the same figure. An output power of 250 and 110 mW was obtained at 12 and 16 GHz, respectively, both with an associated gain of 8 dB.

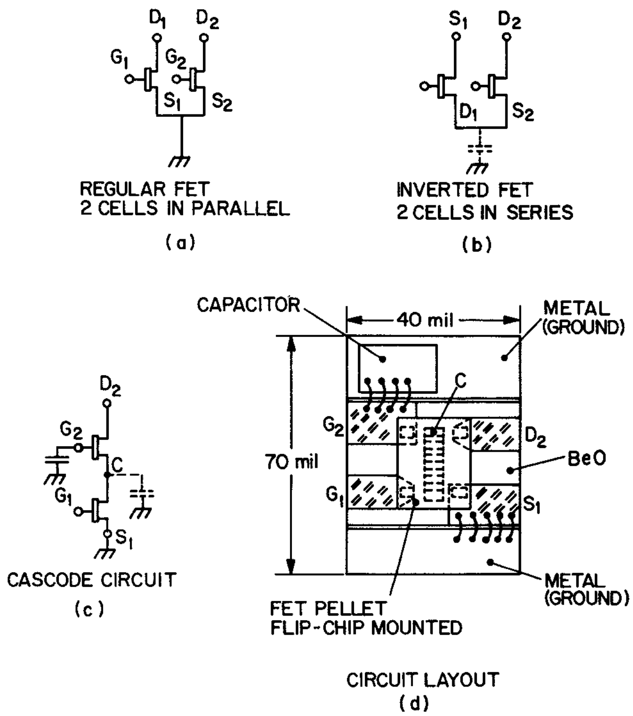

Fig. 7. Cascode Amplifier Circuit Layout

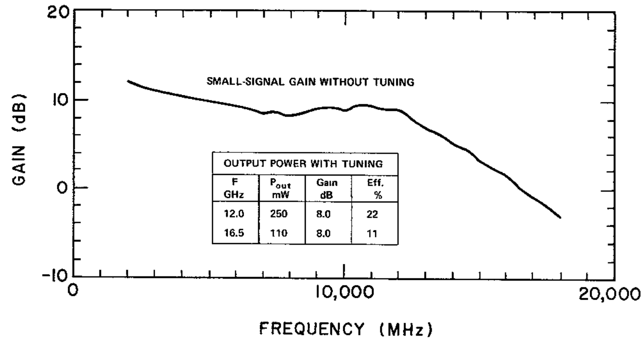

Fig. 8. Performance of Cascode Amplifier

Conclusions

The new miniature BeO circuits technology offers excellent electrical and thermal properties for power amplifier applications, the possibility for batch processing of circuits separate from devices, and a very small circuit size that approaches that of the monolithic counterparts. The process is highly flexible which makes it suitable for small-to-moderate quantities at frequencies ranging from UHF to Ku-band. The fabrication and assembly processes involved are in principle well reproducible and suitable for low-cost production.

Experimental results illustrate the basic viability of this approach: the performances obtained from 1/2-W and 1-W amplifiers operating at Ku-band are already better than those obtained by more standard technologies. A cascode amplifier, also built on BeO has shown exceptionally broadband performance.

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