Conclusion: In this Letter, we have introduced a new composite device, the BFET, which inherits the best characteristics of both the MOSFET and BJT. By using the new BFET as a basic building block, many circuits can be implemented, and the new BiCMOS synthesis method developed of particular interest will be the application of the new cell in log-domain circuits [4] and switched-current filters [5].

Acknowledgment: We thank Northern Telecom for their device models and technical support. C. Toumazou is very grateful to the British Government for the Overseas Research Student Award.

11 June 1996
Electronics Letters Online No: 19961276

Thart Fah Voo and C. Toumazou (*Department of Electrical Engineering, Imperial College, Exhibition Road, London SW7 2BT, United Kingdom*)

References

1 CAMENZIND, H.R., and GREBENE, A.B.: 'An outline of design techniques for linear integrated circuits', *IEEE JSSC*, 1969, **4**, (3), pp. 110–122

2 GRAY, P.R., and MEYER, R.G.: 'Analysis and design of analog integrated circuits' (Wiley, 1984, 2nd edn.)

3 LAKER, K.R., and SANSEN, W.M.C.: 'Design of analog integrated circuits and system' (McGraw Hill Inc., 1994)

4 FREY, D.R.: 'Log-domain filtering: an approach to current-mode filtering', *IEE Proc. G*, 1993, **140**, (6), pp. 406–416

5 TOUMAZOU, C., HUGHES, J.B., and BATTERSBY, N.C.: 'Switched-currents: An analog technique for digital technology' (IEE, 1993)

GaAs low-high doped MESFET MMIC power amplifier for CDMA/AMPS dual-mode cellular telephone

T.M. Roh, Y. Suh, B. Kim, W. Park, J.B. Lee, Y.S. Kim and G.Y. Lee

Indexing terms: Gallium arsenide, MESFET, MMIC, Power amplifiers, Code division multiple access, Cellular radio

An MMIC power amplifier using low-high doped GaAs MESFETs (LH-MESFETs) has been developed for a CDMA/AMPS dual mode cellular telephone. It is fully integrated on one chip (2.5×2.9mm^2) including all matching circuits. For CDMA operation at frequency of 836.5MHz, an efficiency of 25%, adjacent channel leakage power of –29dBc at 885kHz, and –48dBc at 1980kHz were obtained with an output power of 27.25dBm and V_{dd} = 4.7V. In AMPS operation, 30.5dBm output power was obtained with 27.5dB gain and 47% efficiency. The experimental results show that the gate periphery of LH-MESFETs and size of MMIC are much smaller than in previously reported similar amplifiers using conventional MESFET technology. This MMIC power amplifier is suitable for dual mode cellular applications.

Introduction: In cellular telephones, both analogue and digital communications are now in service, and handsets operating on CDMA/AMPS dual-mode are needed. The power amplifier for a CDMA/AMPS handset should be small, with very linear characteristics, high efficiency, and low cost. GaAs MESFETs are commonly used for highly efficient linear power amplifiers [1]. Heterostructure devices such as HBTs and *p*-HEMTs have better linearity and efficiency than MESFETs, and have also been used in dual-mode power amplifiers [2–5]. These amplifiers usually have hybrid output matching circuits. Monolithic integration however is the research trend because systems are required to be lighter and have higher integration levels at lower cost. The GaAs MESFET represents the most mature technology for MMIC and is more cost-effective than HBTs or *p*-HEMTs. The LH-MESFET has better linearity than a conventional MESFET, and has strong potential for use in high efficiency linear power amplifiers.

This Letter reports a CDMA/AMPS dual mode power amplifier based on the LH-MESFET. It is fully integrated into one chip, including all matching circuitry. This MMIC amplifier has low adjacent channel leakage power (P_{adj}) and high efficiency under both digital and analogue operation.

Amplifier characteristics:
(i) *Device*: To obtain a CDMA/AMPS dual-mode power amplifier, it is important to develop a highly efficient linear power MESFET. The LH-MESFET is a good candidate for this purpose. The structure consists of a thin active layer doped to mid 10^{17}/cm^3 (highly-doped layer), a thick active layer doped to mid 10^{16}/cm^3 (low-doped layer), and an undoped GaAs layer for surface passivation. The highly-doped layer acts as a main channel for carriers, and is made thin to obtain a uniform and high transconductance under class AB bias conditions.

Table 1: Two-tone test results of LH-MESFET and conventional MESFET (C-MESFET) operating at 836MHz

	LH-MESFET	C-MESFET
Device size	10.8mm	12mm
Drain bias	4.7V, 430mA	4.7V, 430mA
I_{dss}	2.2A	2.4A
Output power	27.4dBm	27.4dBm
IMD$_3$	–30dBc	–24dBc
Efficiency	27%	27%

To compare the potential of the LH-MESFET as a linear power device, two-tone testing was carried out on both an LR-MESFET and ion-implanted MESFET. The measured characteristics using the load-pull method are shown in Table 1. The two devices on test have comparable performance, except for the IMD$_3$ level. This better linear performance of the LH-MESFET makes it possible to use smaller FETs.

(ii) *Amplifier design*: We have designed the amplifier using the large signal model of an LH-GaAs MESFET, with the modified-Curtice current model, constructed from S-parameter, pulsed-IV, and thermal measurements. To reduce chip size and improve yield, we focused on reducing the total gate width of the output-stage FET by optimising the gate bias and load impedance.

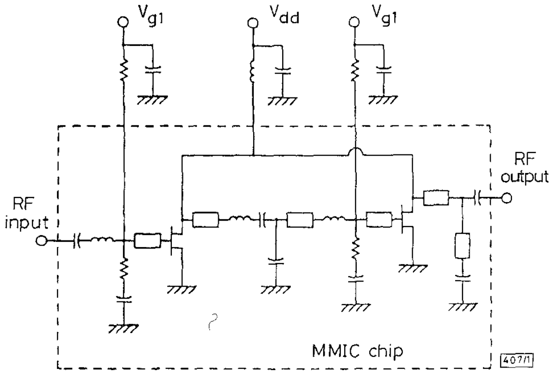

Fig. 1 *Circuit diagram of dual-mode MMIC power amplifier*

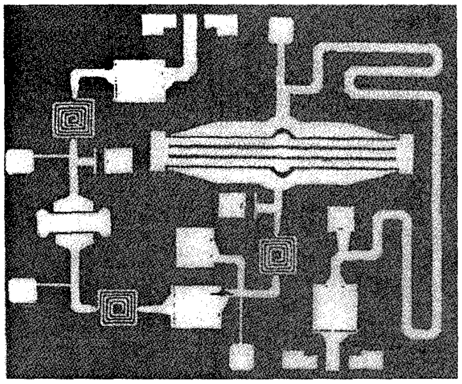

Fig. 2 *Photograph of fabricated MMIC power amplifier (2.5×2.9mm^2)*

Fig. 1 shows the two-stage power amplifier design. Owing to the good linearity of LH-MESFET, we could design the amplifier using a small FET and simple L-C matching circuit topology. Other complex matching techniques such as feedback or harmonic tuning are not used because they are unsuitable for small MMICs. The gate periphery of the 1st FET is 1.5mm with a gate length of 0.8µm. The second stage FET has 10.8mm of gate periphery (225µm unit gate finger), 0.8µm of gate length, and 10.5GHz of f_{max}. These FETs are much smaller than in previously reported work using ion-implanted FETs [1]. The drain bias circuit was fabricated using off-chip inductors and capacitors. Fig. 2 shows the fabricated MMIC chip (2.5 × 2.9mm²).

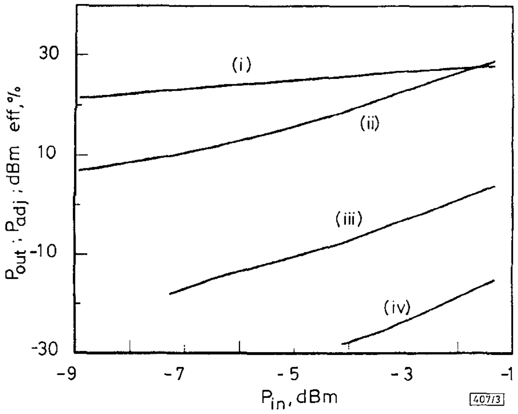

Fig. 3 *P_{adj}, η and P_{out} of MMIC power amplifier under digital operation*

(i) P_{out} output power
(ii) η power added efficiency
P_{adj} Adjacent channel leakage power
(iii) P_{adj} at 885kHz
(iv) P_{adj} at 1980kHz
V_{dd} = 4.7V
Input signal: 836.5MHz, offset QPSK modulation, P_{adj}: at 885kHz and 1985kHz apart from 836.5MHz

(iii) *Measured results*: Fig. 3 shows P_{adj}, output power, and efficiency of the power amplifier at a supply voltage V_{dd} = 4.7V. For CDMA operation mode, an efficiency of 25%, low P_{adj} of –29dBc at 885kHz, and -48dBc at 1980kHz were obtained, with a gain of 30.5dB at an output power of 27.25dBm. For AMPS operation mode, the amplifier showed an output power of 30.5dBm with an efficiency of 47%. The input VSWR was 2:1. The measured characteristics of the dual-mode power amplifier are summarised in Table 2. The characteristics of our MMIC are comparable to those of partially integrated amplifiers based on HBTs or *p*-HEMTs [2, 3] whose input and output matching circuits are in hybrid form.

Table 2: Measured results of MMIC power amplifier

Common specifications	
Frequency range	824–849MHz
Chip size	2.5 × 2.9mm²
VSWR	2:1 max
Small signal gain	30.5dB
Supply voltage	4.7V
CDMA mode (*f* = 836.5MHz, P_{out} = 27.25dBm)	
Gain linearity (<27dBm)	<±0.2dB
P_{adj} (885kHz offset)	29dBc
P_{adj} (1980kHz offset)	48dBc
Power added efficiency	25%
AMPS mode (*f* = 836.5MHz, P_{in} = 3.5dBm)	
Output power	30.5dBm
Power added efficiency	47%

Conclusions: An MMIC power amplifier operating at 4.7V has been developed for CDMA/AMPS dual-mode cellular telephone applications using LH-MESFETs. Owing to the good linear properties of the FET, the gate peripheries of first and second stage FETs are small, 1.5 and 10.8mm, respectively. The size of MMIC, with all matching circuits, is quite small (2.5 × 2.9mm²). In CDMA operation at a frequency of 836.5MHz, efficiency of 25%, low P_{adj} of –29dBc at 885kHz, and –48dBc at 1980kHz were obtained at an output power of 27.25dBm. In AMPS operation, an output power of 30.5dBm was obtained at a gain of 27.5dB and efficiency of 47%. The experimental results show that the gate periphery of the LH-MESFET and the size of MMIC are rather small compared with those of previously reported similar amplifiers using ion-implanted MESFETs. The low adjacent channel leakage power and high efficiency under both digital and analogue operation are the features of the MMIC amplifier.

13 August 1996
Electronics Letters Online No: 19961280

T.M. Roh, B. Kim and W.S. Park (*Department of Electronic and Electrical Engineering, Microwave Application Research Center, Pohang University of Science and Technology, San 31, Hyoja-Dong, Pohang, Kyungbuk, 790-784, Korea*)

Y. Suh (*Department of Electronic Engineering, Yeungnam University, 214-1, Dae-Dong, Kyongsan, Kyungbuk, 712-749, Korea*)

J.B. Lee, Y.S. Kim and G.Y. Lee (*Samsung Microwave Semiconductor, 1530 McCarthy Blvd, Milpitas, CA, 95035, USA*)

References

1 MASATO, H., MEADA, M., FUJIMOTO, H., MORIMOTO, S., and NAKAMURA, M.: 'Analogue/digital dual power module using ion-implanted GaAs MESFETs'. IEEE MTT-S Int. Microw. Symp. Dig., 1995, Vol. 2, pp. 567–570

2 'RI21002 CDMA/TDMA HBT power amplifier datasheet' (Rockwell, 1995)

3 CARDULLO, M., DOUGLAS, E., GOFF, M., GRIFFITHS, J., HARRINGTON, K., KAISER, J., LESAGE, S., and PENGELLY, R.: 'Transmitter chips for use in a dual-mode AMPS/CDMA chip set', *Microw. J.*, 1996, **39**, (3), pp. 60–72

4 BOUTHILLETTE, S., and PLATZKER, A.: 'High efficiency L-band variable output power amplifiers for use in communication system'. IEEE MTT-S Int. Microw. Symp. Dig., 1996, Vol. 2, pp. 563–566

5 ONO, H., UMEMOTO, Y., MORI, M., MIYAZAKI, M., TERANO, A., and KUDO, M.: 'Pseudomophic power HEMT with 53.5% power-added efficiency for 1.9-GHz PHS standards'. IEEE MTT-S Int. Microw. Symp. Dig., 1996, Vol. 2, pp. 547–550

6 LEE, J.L., KIM, H., MUN, J.K., KWON, O., LEE, J.J., PARK, H.M., and PARK, S.C.: '3.3V operation GaAs power MESFET with 65% power-added efficiency for hand-held telephone', *Electron. Lett.*, 1994, **30**, (9), pp. 739–740

High voltage (450V) 6H-SiC lateral MESFET structure

D. Alok and B.J. Baliga

Indexing terms: MESFET, Silicon carbide

A high voltage 6H-SiC lateral MESFET has been fabricated using a three mask process. Selective ion implantation was used to create the conducting layer (N-region) demonstrating the RESURF effect in SiC for first time, as well as easy isolation and edge termination. This MESFET was able to withstand a forward blocking voltage of 450V at a gate voltage of -20V. The specific on-resistance and transconductance for a device with a drain gate separation of 15µm was found to be 83mΩ cm² and 2mS/mm, respectively.

Introduction: Silicon carbide (SiC) has been projected to be an excellent semiconductor for high power, high frequency and radiation hard applications [1]. The critical electric field for breakdown in 6H-silicon carbide is about 10 times higher than that of silicon,