Simulating the wireless channel: The transmission and reception of the compressed bands through a CDMA wireless channel is depicted in Fig. 1. The actual simulation was carried out using Cadence's signal processing software SPW. Unlike the TDMA technique, CDMA technology allows for the transmission of all coded bands at the same time. However, to avoid complexity of the diagram, the transmission of only one band is shown in Fig. 1. But during actual simulation of the channel, two coded bands were transmitted simultaneously. Walsh codes 1 to 4 have been used to separate data of one band from the other band.

Once the image has been compressed by the image coder, it is error-protected by using a convolutional code (2, 1, 5), $n = 2$; $k = 1$; $m = 5$. Furthermore, to combat the burst errors associated with a fading channel, the error-protected data are interleaved. Interleaving spreads out the data in time so that burst errors are spread out to appear independent making a bursty channel similar to an AWGN channel. The interleaved data are modulated using a QPSK modulator and the in-phase and quadrature components of the output are spread by PN sequences. The spreading factor is 128 as specified by the IS-95A standard with bit rates of 9600 bit/s and a chip rate of 1.2288 Mchip/s. Walsh functions from 1 to 4 are used for the four bands. A square root raised cosine filter with a roll-off factor of 0.35 is used for pulse shaping and the data are fed through a frequency selective multipath-fading channel. White noise corresponding to 18 dB channel SNR is added to the output of the fading channel. At the receiver end, the data are again filtered by the same filter used for pulse shaping. Despreading takes place and the despread data are demodulated. The deinterleaver is used to reorder the data back to their original sequence. After passing through a convolutional decoder, the data are sent to the image decoder for reconstruction of an approximation of the original frames.

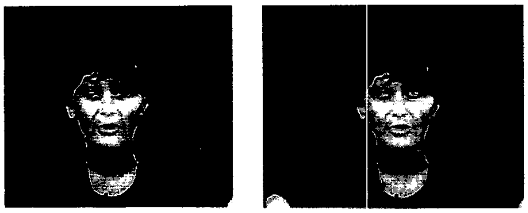

Fig. 2 *Two original consecutive frames of Miss America sequence*

a Frame 5
b Frame 6

The tests were performed on a grey-scale sequence of Miss America having 288 × 360 pixels per frame at a rate of 30 frame/s Two frames with distinct motion in the eyes and lips area were chosen as data for channel simulation. The original frames, frames 5 and 6, are shown in Fig. 2 for comparison. In the absence of channel errors, the only information loss in the reconstructed frames is due to the compression involved. It is seen that the coding scheme produces results comparable to the original data with very slight deterioration around the edges and in the motion information. The PSNR of the reconstructed frames is 36.51 and 36.52 dB, respectively, at 0.25 bit/pixel.

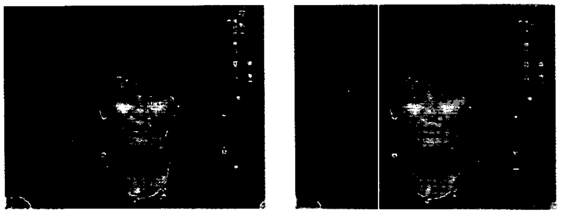

Fig. 3 *Reconstructed frames at 0.25 bit/pixel and vehicle speed of 65 mph with channel SNR 18 dB*

a Frame 5
b Frame 6

Fading errors are introduced in the IS-95 channel by increasing the vehicle speed to 65 mph, which is a typical highway speed, and with a channel SNR of 18 dB. The corrupted frames are reconstructed and shown in Fig. 3. The PSNR of the reconstructed frames, after the introduction of fading errors, reduces to 27.26 and 27.21 dB, respectively. The major contributor to the overall degradation in these frames is the baseband. Any burst errors in the lower levels of the pyramid have less effect on the picture quality.

© IEE 2000 *23 September 1999*
Electronics Letters Online No: 20000383
DOI: 10.1049/el:20000383

A.Kh. Al-Asmari (*Department of Electrical Engineering, King Saud University, Riyadh, 11421, Saudi Arabia*)

E-mail: akasmari@ksu.edu.sa

D. Arya and S.C. Kwatra (*Department of Electrical Engineering and Computer Science, The University of Toledo, Toledo, Ohio, USA*)

References

1 AL-ASMARI, A.KH., SINGH, V.J., and KWATRA, S.C.: 'Hybrid coding of images for progressive transmission over a digital cellular channel'. IEEE/CISST'99, Monte Carlo Resort, Las Vegas, Nevada, 28 June–1 July 1999

2 VITERBI, A.J.: 'The evolution of digital wireless technology from space exploration to personal communication services', *IEEE Trans.*, 1994, **43**, (3), pp. 638–644

3 PRICE, R., and GREEN, P.E.: 'A communication technique for multipath channels', *Proc. IRE*, 1958, **46**, pp. 555–570

4 AL-ASMARI, A.KH.: 'Optimum bit rate coding with low computational and memory requirements', *IEEE Trans. Circuits Syst. Video Technol.*, 1995, **5**, (3), pp. 182–192

5 AHALT, S.C., KRISHNAMURTHY, A.K., CHEN, P., and MELTON, D.E.: 'Neural networks for VQ of speech and image', *IEEE J. Sel. Areas Commun.*, 1990, **8**, (8), pp. 1449–1457

Broadband lumped HBT amplifiers

S. Krishnan, D. Mensa, J. Guthrie, S. Jaganathan,
T. Mathew, R. Girish, Y. Wei and M.J.W. Rodwell

The authors report the realisation of wideband amplifiers using AlInAs/GaInAs transferred-substrate heterojunction bipolar transistors (HBTs). The first amplifier is in the f_τ doubler configuration with an input emitter follower while the second is a Darlington stage designed for high gain. The former had a low frequency gain of 8.2dB and a 3dB bandwidth of 80GHz, while the latter had a low frequency gain of 18dB and a bandwidth of 50GHz.

Introduction: Applications for heterojunction bipolar transistors (HBTs) include RF/microwave analogue to digital conversion and fibre-optic transmission in the range 40–120 Gbit/s. A first step in the development of these systems is the design of simple broadband amplifiers that constitute the gain blocks for these mixed-signal ICs.

Technology: The amplifiers reported here use HBTs fabricated in a substrate transfer process [1]. The process provides a microstrip wiring environment on a low ε_r substrate and efficient heatsinking for devices operating at high current densities. The transistors used in the work had a 40 nm base and 300 nm collector thickness and had 1 μm wide emitters and 1.8 μm wide collector-base junctions. From RF measurements, the HBT f_τ and f_{max} are 180 and 320 GHz, respectively.

Circuit design: In the mirror doubler amplifier (Fig. 1*a*) the transistor Q_1 operates as an emitter follower while Q_2, Q_4 and Q_5 constitute an f_τ doubler in the current mirror configuration [2]. The diode-connected transistor Q_3 maintains the V_{ce} of Q_5 near the region of peak RF performance. In addition to providing bias current for Q_1, R_{EF} provides shunt loading of the emitter follower output to prevent gain peaking. The extrinsic transconductance of the mirror doubler configuration is set by the bias current of Q_4 and Q_5; together with R_f, these parameters are chosen to provide the required gain and 50 Ω input and output impedance, according to the relationships $R_f = Z_0(1 - A_v)$ and $(R_{ex4} + kT/qI_{E4}) = (R_{ex5} + kT/qI_{E5}) = Z_0/2(1 - A_v)$, where R_{ex4} and R_{ex5} are the parasitic emitter resistances, $Z_0 = 50\Omega$, and A_v is the low frequency gain. The bias currents and device sizes are as shown in Fig. 1. For the Darlington amplifier (Fig. 1*b*) transistor Q_1 operates as an emitter follower driving Q_2. In this case, $(R_{ex2} + kT/qI_{e2}) = Z_0(1 - A_v)$ and R_f is as given previously. For each HBT, increasing the transistors' emitter stripe lengths increases C_{cb} but decreases R_{bb}; the stripe lengths are individually chosen to maximise the circuit bandwidth. IC photographs are shown in Fig. 2.

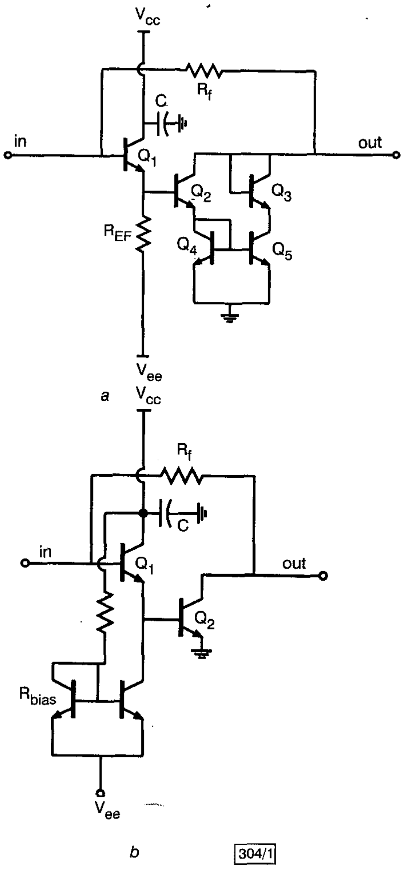

Fig. 1 *Schematic circuit diagrams of mirror doubler amplifier and high gain Darlington amplifier*

W_c, L_c, We and L_e are widths and lengths of collector and emitter junctions; J_e is emitter current density
a Mirror doubler amplifier Q_1, Q_2, Q_3, Q_4: $W_e \times L_e = 1 \times 8\mu m^2$, $W_c \times L_c = 1.8 \times 18\mu m^2$, $J_e = 2 \times 10^5 A/cm^2$; Q_5: $W_e \times L_e = 1 \times 16\mu m^2$, $W_c \times L_c = 1.8 \times 30\mu m^2$, $J_e = 1 \times 10^5 A/cm^2$
b High gain Darlington amplifier Q_1: $W_e \times L_e = 1 \times 18\mu m^2$, $W_c \times L_c = 2 \times 20\mu m^2$, $J_e = 8.3 \times 10^4 A/cm^2$; Q_2: $W_e \times L_e = 1 \times 18\mu m^2$, $W_c \times L_c = 2 \times 20\mu m^2$, $J_e = 1.1 \times 10^5 A/cm^2$

Fig. 2 *IC chip photographs of mirror doubler amplifier and high gain Darlington amplifier*

a Mirror doubler amplifier
b High gain Darlington amplifier

Results: The amplifier S-parameters were measured on wafer using 0.5–50GHz and 75–110GHz network analysers (Fig. 3). For the mirror-doubler, the low frequency gain is 8.2dB and the 3dB bandwidth is 80GHz. There is no observed gain peaking. For the Darlington amplifier, the low frequency gain is 18dB and the 3dB bandwidth is 50GHz. The input and output return losses are relatively poor at high frequencies; one demonstrated solution is to add a single-HBT input stage designed for low gain but good input return loss [3].

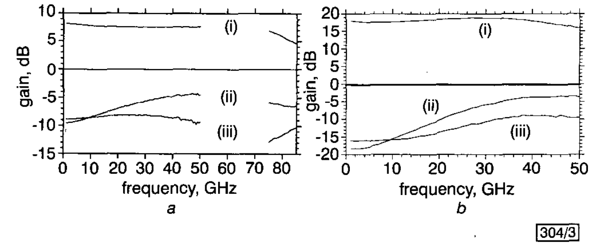

Fig. 3 *S parameter measurements of mirror doubler amplifier and high gain Darlington amplifier*

a Mirror doubler amplifier
b High gain Darlington amplifier
(i) S_{21}
(ii) S_{11}
(iii) S_{22}

Conclusions: We have demonstrated broadband amplifiers with low frequency gains of 8.2 and 18dB and bandwidths of 80 and 50GHz, respectively, by using mirror-doubler and Darlington stages with resistive feedback. These compact amplifiers have applications in wideband microwave communication systems and mixed-signal ICs.

Acknowledgments: These results would not have been possible but for the guidance of Q. Lee, now at Lucent Technologies. This work was supported by the ONR under grant N00014-98-1-0068.

6 January 2000
Electronics Letters Online No: 20000355
DOI: 10.1049/el:20000355

S. Krishnan, J. Guthrie, S. Jaganathan, T. Mathew, R. Girish, Y. Wei and M.J.W. Rodwell (*Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93106, USA*)

E-mail: pks@vsat.ece.ucsb.edu

D. Mensa (*Conexant Systems, Inc., 2427 W. Hillcrest Drive, Newbury Park, CA 91320, USA*)

References

1 MENSA, D., PULLELA, R., LEE, Q., GUTHRIE, J., MARTIN, S.C., SMITH, R.P., JAGANATHAN, S., MATHEW, T., AGARWAL, B., LONG, S.I., and RODWELL, M.: 'Transferred substrate HBTs with 254GHz f_T', *Electron. Lett.*, 1999, **35**, (7), pp. 605–606

2 ARMIJO, C.T., and MEYER, R.G.: 'A new wideband Darlington amplifier', *IEEE J. Solid State Circuits*, 1989, **SC-24**, pp. 1105–1109

3 HUBER, A., HUBER, D., BERGAMASCHI, C., MORF, T., and JACKEL, H.: 'Design and characterization of a 50GHz InP/InGaAs HBT amplifier'. 11th Int. Conf. Indium Phosphide and Related Materials, Davos, Switzerland, 16–20 May 1999, pp. 191–194