New rf silicon

Loek Colussi discusses a new bipolar rf transistor technology that rivals GaAs in digital cellular and cordless phone applications.

A new generation of high-performance silicon bipolar rf transistors with transition frequencies in excess of 20GHz has been developed by Philips Semiconductors. These devices are intended for use in low-voltage cordless and cellular telephones.

In addition to small-signal types for use in a phone's rf receiver, these fifth-generation rf wideband transistors include medium-power types. These rival the performance of GaAs devices when used for rf power amplification in a telephone's transmitter. Unlike GaAs devices, however, they operate at high efficiency from a single supply rail – considerably reducing circuit complexity and allowing the design of smaller, lighter, portable phones.

The key to reducing the size and weight of a portable telephone is the use of a smaller battery pack. In order to maximise energy density, this usually means using fewer cells and consequently a lower supply voltage, typically between 3 and 3.6V. Ideally, the entire telephone should then operate from this single supply voltage. Although dc-to-dc converters can be used to create higher supply voltages, they inevitably result in efficiency losses which shorten the telephone's standby and talk times. They also occupy valuable pc board area and increase the telephone's component and assembly costs.

Because the most power-hungry part of a cellular or cordless telephone is its rf power amplifier, it is important that any move to lower supply voltages does not result in a significant loss of efficiency in the power amplifier. The power amplifier should operate at low voltage with high power-added efficiency – i.e. the ratio of rf output power to dc + rf input power. In order to keep component and assembly costs low, it should use as few gain stages as possible and the minimum number of peripheral components. To reduce test time, it should be alignment-free and provide predictable, reliable, performance.

Figure 1 illustrates how Philips Semiconductors' new wideband rf transistors can be used to meet these objectives in an rf power amplifier for DECT telephones. The design operates from a single 3.6V rail and includes bias circuitry for load power adjustment and on/off switching. In addition, it occupies less than 10 by 20 mm of a standard two-layer FR4 laminate pc board.

The amplifier delivers 26dBm output power, achieving a power gain of 29 dB and an overall power added efficiency in excess of 50%.

Amplifying rf power

RF power amplification is achieved using only two of the new wideband devices. Transistor Q_1 – a *BFG425W* – operates in class-A mode at a V_{CE} of 3V and a collector current of 30mA. Under these conditions it provides 18dB of gain and an output power level of

Table 1. Measured source and load impedances of the devices used in the DECT power amplifier.

Transistor	Source imp. (Ω)	Load imp. (Ω)	Conditions
BFG425W	(12+0.7j)	(52+102j)	V_{CE}=3.0V; I_C=30mA; f=1.9GHz
BFG21W	(9.1–9.5j)	(9.7–6.4j)	V_{CE}=3.6V; P_o=26dBm; f=1.9GHz

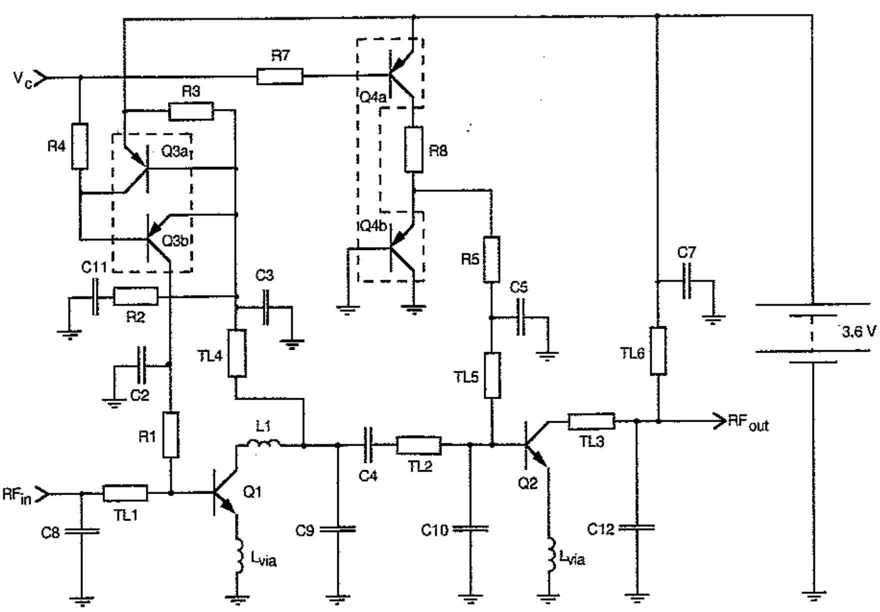

Fig. 1. DECT phone power amplifier using new fifth-generation rf wideband transistors.

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15dBm for –3 dBm rf input.

Transistor Q_2 is a *BFG21W* medium-power transistor operating in class-AB mode. It drives the telephone's antenna circuit directly. Biased to a base voltage of 0.7V, which results in a quiescent collector current of approximately 1mA, this transistor provides a power gain of 11dB and 26dBm output level.

Under these conditions its collector efficiency is typically 55%.

The measured source and load impedances of the transistors operating under the conditions described above appear in **Table 1**.

Impedance matching networks are therefore required to provide smooth 50Ω matching throughout the amplifier.

Impedance matching

The impedance matching part consists of three separate sections – the input, interstage and output matching networks. Its purpose is to enable the rf transistors to perform optimally with respect to power gain, output power and efficiency.

Fortunately, the inherent impedance levels of the *BFG425W* and *BFG21W* as indicated above are not exceptionally high or low, so they are quite easy to match.

At the input, shunt capacitor C_8 and series microstrip line TL_1 match the 50Ω rf source to the base of Q_1. Base resistor R_1 is used for biasing and has no effect on matching. Between the collector of Q_1 and the base of Q_2, matching is done by series inductor L_1, shunt capacitor C_9 and series transmission line TL_2.

If pcb area is not critical, L_1 can be replaced by a 3.5mm, 50Ω transmission line. Shunt capacitors C_9 and C_{10} partly compensate the influence of bias stubs TL_4 and TL_5, which are both $<\lambda/4$.

At the output side of Q_1, series network R_2/C_{11} is used to increase the k-factor of the first stage to avoid potential instability below 1GHz. The output match is done by series transmission line TL_3 and shunt capacitor C_{12}. Again this capacitor also compensates the influence of bias stub TL_6.

Biasing

The biasing part of the power amplifier incorporates a pair of *PUMT1* dual p-n-p transistors, $Q_{3,4}$. To define the collector current in Q_1, Q_{3a} compares the voltage across R_3 with the forward voltage of its base-emitter junction.

If current in R_3, i.e. Q_1's collector current, increases, Q_{3a} starts to conduct. This reduces the base drive to Q_{3b} which in turn reduces the base drive to Q_1, thereby stabilising Q_1's collector current.

For this circuit to work, control voltage V_C has to be fixed to ground. Voltage on the col-

Double-poly transistor technology

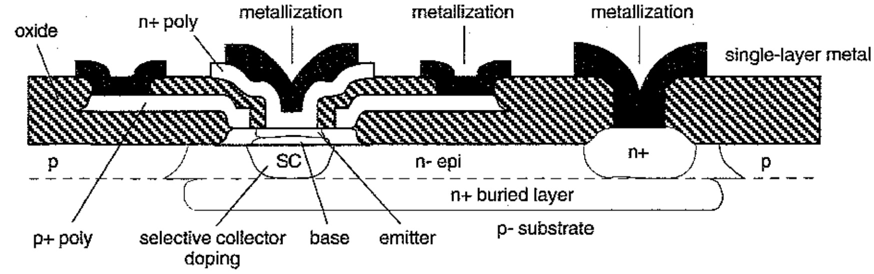
Philips Semiconductors' fifth-generation rf wideband transistors are based on a double-polysilicon buried-layer process that yields bipolar transistors with transition frequencies (f_T) in excess of 20GHz at low V_{CE} voltages. Typical power gains of 11dB at 2GHz allow these transistors to be used in the latest generation of digital cordless and cellular telephones – an application previously dominated by GaAs devices.

To produce bipolar transistors with cut-off frequencies above 20GHz that will operate at V_{CE} voltages of 3V or less, it is necessary to achieve base widths in the order of 100 nm. This is accomplished by using the double-polysilicon transistor structure illustrated below, in which deposited polysilicon is used for both the base and emitter connections.

Very steep doping profiles in the base and emitter regions create the very narrow base widths required for a high cut-off frequency, while sub-micron emitter widths of typically 0.5μm – made possible by the self-aligned nature of the process – ensure a high f_{max}. These sub-micron emitter widths also prevent current crowding effects and help to keep the base resistance low, thereby preventing degradation of power gain. Lateral connections to the base region by p+ polysilicon also help to reduce base resistance and minimise collector-base (Miller) capacitance.

The n+ layer required for the collector is buried within a p- substrate that is connected to the emitter. This enables the transistor die to be bonded directly to the transistor's emitter lead-outs, reducing its emitter inductance and the thermal resistance of the SOT343R plastic surface-mount package. Large area metallisations for the emitter allow the transistors to handle the high emitter current densities required in medium-power types.

Philips Semiconductors' family of fifth-generation rf wideband transistors currently includes five types. The *BFG403W, BFG410W* and *BFG425W* are small signal types optimised for maximum f_T at collector currents of 3mA, 10mA and 25mA respectively. They feature gains of over 20dB at 2GHz and noise figures as low as 1.2dB. The two medium power transistors in the range are the *BFG480W* and *BFG21W*, which have their maximum f_T values at collector currents of 80mA and 250mA respectively. They provide power gains at a frequency of 2GHz and a V_{CE} of 3.6V in excess of 14dB and 11dB respectively. Both types achieve typical power added efficiencies greater than 60%.



New wideband bipolar transistors are based on a double-polysilicon buried-layer process yielding transition frequencies (f_T) in excess of 20GHz combined with low V_{CE} voltages.

Components for the DECT power amplifier.

R_1	560
R_2	10
R_3	18
R_4	100k
R_5	10
R_6	not required
R_7	10k
R_8	180
L_1	1n8
C_1	not required
C_2	10n
C_3	8p2
C_4	8p2
C_5	8p2
C_6	not required
C_7	8p2
C_8	1p8
C_9	1p8
C_{10}	2p7
C_{11}	10n
C_{12}	2p7
Q_1	BFG425W
Q_2	BFG21W
Q_3	PUMT1
Q_4	PUMT1
TL_1	Length 6.5mm; Width 0.5mm
TL_2	Length 3.0mm; Width 1.2mm
TL_3	Length 4.5mm; Width 0.5mm
TL_4	Length 7.5mm; Width 0.2mm
TL_5	Length 7.5mm; Width 0.2mm
TL_6	Length 6.5mm; Width 0.2mm

lector of Q_1 is always 0.6V lower than the supply rail, allowing a 3V collector voltage swing.

The base of class-AB output stage Q_2 is biased by a low impedance voltage source formed by Q_{4b}. The temperature coefficient of Q_{4b}'s base-emitter voltage is roughly the same as that for Q_2, maintaining a quiescent current of approximately 1mA in Q_2's collector – despite ambient temperature changes.

Resistor R_5 prevents thermal runaway of Q_2. Transistor Q_{4a} is driven by control input V_C to cut off the base drive to Q_2 during the interval between rf output pulses.

When used in pulsed mode at nominal supply voltage and output level, the load can be mismatched to a voltage/standing-wave ratio less than or equal to 6:1, in all phases, without damage. The power amplifier can also be operated in CW mode provided that 50Ω output matching can be guaranteed under all conditions.

It is possible to increase overall efficiency of the amplifier by a few percent by operating the *BFG425W* in class-AB mode rather than in class-A mode. This also simplifies the biasing circuitry. However, it has the negative effect of reducing the overall power gain, resulting in the need for a higher rf drive level in order to achieve the required 26dBm output power.

If a multi-layer pc board is used, the area occupied by the amplifier can be reduced by burying the transmission lines in the board. Space can be saved by placing the biasing circuitry on the reverse side of the pc board. Inductance of the vias which connect the emitter lead-outs of Q_1 and Q_2 to the ground plane on the reverse of the pc board must be kept lower than 0.1nH in order to maintain rf performance.

PHS-phone applications

With only minor modification this power amplifier is also suitable for use in PHS phones. Although they require a lower rf output power of 21dBm rather than 26dBm, such phones need better linearity performance. To achieve the required linearity, the collector current in the *BFG425W* is reduced to 20mA while the quiescent current through the *BFG21W* is increased to 10mA. In this way, both transistors operate on a more linear part of their gain characteristic.

The *BFG425W*'s collector current can be suitably decreased by increasing the value of R_3 to 22Ω. To increase the quiescent current in the *BFG21W*, the base potential of Q_{4b} is increased by adding a potential divider between the positive supply rail and ground. A divider comprising 330Ω to ground and 18kΩ to V_S works well, although other values can be used to achieve an optimum trade-off between linearity and efficiency. ■

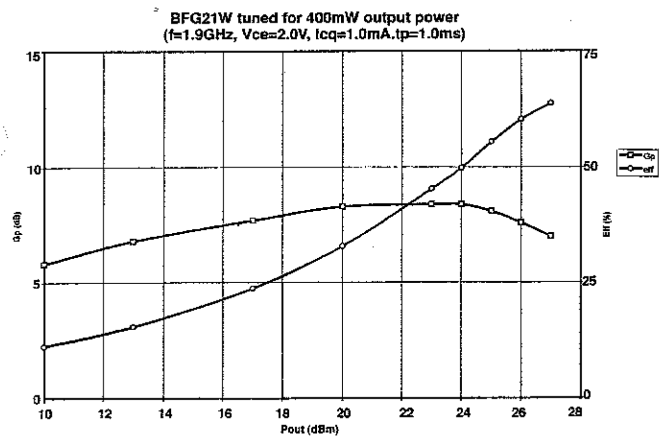
Power gain – even at 2V

Experiments using a scaled-up version of Philips Semiconductors' *BFG21W* double polysilicon rf transistor indicate that this technology can be used to design DECT power amplifiers that operate from 2.4V battery packs.

As indicated in **a)** below, the transistors tested provide a power gain, G_p, of 7dB at the required 27dBm DECT output power level when operating with a V_{CE} of only 2.0 V. Equally impressive, their power added efficiency at this output level is almost 64%, allowing 2.4V DECT telephones to achieve long standby and talk times.

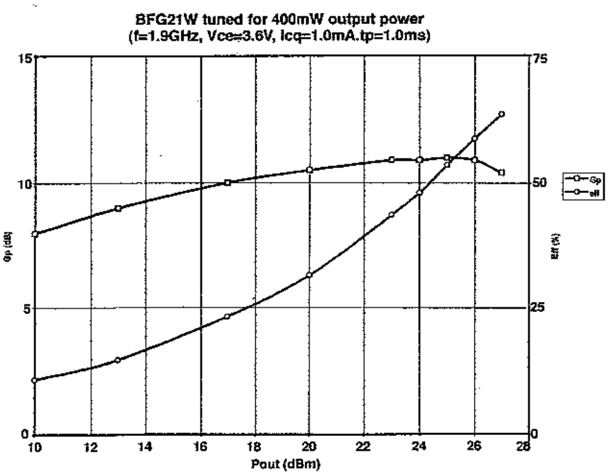
To compensate for the lower power gain of the output stage at 2.0V (7dB compared to the 10.5dB shown in **b)** for a V_{CE} of 3.6V), power amplifiers that use these double-polysilicon transistors would require three gain stages rather than the two described in the main article above. However, the driver and pre-driver stages would each need to provide only 10 to 15dB of power gain in order for the amplifier to be driven at –5dBm.

Detailed test results on the the transistors used in this evaluation can be obtained from Philips Semiconductors' Transistors and Diodes Product Group in Nijmegen, The Netherlands.



Gain and Efficiency vs. P_{out}
f=1.9GHz; Vs=2.0V; Icq=1mA; tp=1.0ms;
tuned for 26dBm output power

P_{out}(dBm)	P_{in} (dBm)	I_c (mA)	G_p (dB)	Eff (%)
10	4.2	45	5.8	11.11111
13	6.2	65	6.8	15.34817
17	9.3	106	7.7	23.64091
20	11.7	152	8.3	32.89474
23	14.6	220	8.4	45.34687
24	15.6	252	8.4	49.83902
25	16.9	285	8.1	55.47856
26	18.4	330	7.6	60.31927
26.5	19.5	350	7	63.81194



Gain and Efficiency vs. P_{out}
f=1.9GHz; Vs=3.6V; Icq=1mA; tp=1.0ms;
tuned for 26dBm output power

P_{out}(dBm)	P_{in} (dBm)	I_c (mA)	G_p (dB)	Eff (%)
10	2	26	8	10.684
13	4	38	9	14.585
17	7	60	10	23.203
20	9.5	88	10.5	31.566
23	12.1	127	10.9	43.641
24	13.1	145	10.9	48.12
25	14	164	11	53.562
26	15.1	188	10.9	58.822
27	16.6	219	10.4	63.57

A Thanks for the tip! Jameco has a number of hard to find parts for older computers, even Apple IIs.

As to your question, the trouble with TTL monitors such as the IBM Monochrome Display is that they're completely obsolete—you can get a complete used monitor cheaper than you can get any spare parts, and if you look in the right places, people are giving old monitors away.

The schematic of the IBM Monochrome Display was published in the *IBM Personal Computer Technical Reference* (1982). It's a single page with no explanatory text. Some newer IBM monitor service manuals can be purchased from http://www.us. pc.ibm. com/cdt/hmm.html, and Service Editor Sam Goldwasser's excellent notes on monitor repair are online at http://www .paranoia.com/~filipg.

Apart from that, there's not much information available. Magazines such as *Computer Hotline* and *Nuts and Volts* used to carry ads for monitor parts and repair guides, but in recent issues the pickings have become very slim. As a last resort, go to the newsgroup sci.electronics. repair and post your questions; if anyone on earth knows, you'll probably find them there.

Half A Digit?

Q *I recently started a course in electronics and am puzzled by a term used when describing the features of digital multimeters. Can you explain what is meant by a "4½ digit display"? — I. J., Trinidad & Tobago*

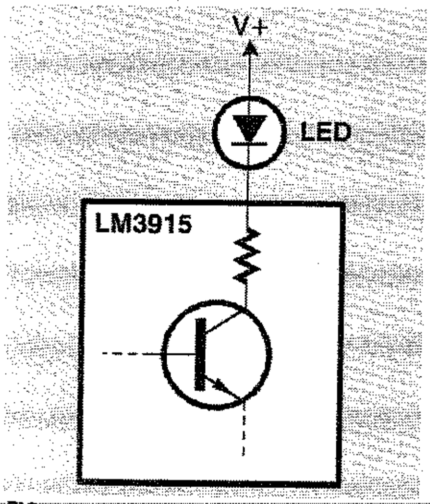


FIG. 4—EACH OF THE LM3915's outputs features an internal switching transistor and a current limiter, which is shown here as a resistor.