A SINGLE CHIP TRANSMITTER FOR A SPREAD SPECTRUM DIRECT SEQUENCE IN-HOUSE COMMUNICATION SYSTEM AT 2.4GHz

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ABSTRACT

The design of a single chip transmitter for a spread spectrum inhouse communication system working at 2.4GHz is presented. The circuit consists of a frequency doubler (1.2 to 2.4GHz), a double balanced modulator with an LO buffer amplifier, and a seven stage power amplifier for 100mW of output power. Except for the power amplifier output matching network, and a bandpass filter, no additional external components are required. Chip fabrication was performed with a commercial 1µm-GaAs-MESFET enhancement/depletion foundry process. Through consequent use of an insensitive circuit design strategy, a high production yield is achieved. From 26 devices investigated, all but one were functional, providing high fundamental suppression without additional filtering. However, a certain output power and temperature sensitivity, together with a high chip-to-chip spread of the carrier suppression, has been observed. At moderate output power levels, about 90% of the devices provided sufficient carrier suppression at less than 1W of power consumption.

Keywords: Single Chip Transmitter, Wireless Data Modem

1. INTRODUCTION

Today considerable effort is spent in the integration of whole systems or at least complex circuits on a single chip or on a set of chips. Thus products become smaller, lighter and, given a large production volume, cheaper than their discrete or hybrid counterparts. In addition, there is an improvement in reliability as a consequence of reduced component count and power dissipation. Furthermore, there is a tendency towards higher carrier frequencies, even for high volume applications such as cordless telephones and radio pagers. Although a number of services planned for the near future operate in the 900MHz band (like GSM), there is a clear demand for the frequency range around 1800MHz. With the commercial availability of stable GaAs-foundry processes, the monolithic integration of products for the mass market working in the higher frequency range on a large scale basis, has reached the scope of system developers.

However, to be competitive with discrete and hybrid techniques, monolithic integration based on GaAs technology must provide significant benefits in size, power consumption, quality, and complexity of the integrated function to compensate for high chip cost. This is only possible if the inherent advantages of the integration on GaAs are fully exploited, and if the drawbacks are circumvented by an appropriate definition of the chip interfaces. Advantages of GaAs technology are: speed, flexibility in the number and the size of FETs and diodes, tracking of devices of the same type on a chip, low parasitic capacitance and, at least for the low GHz range, no distributed effects of the wiring. The main drawback of monolithic technology is the limited Q of passive devices such as capacitors, inductors and transmission lines.

The subject to be covered in this paper is the transmitter section of a wireless data modem for inhouse application. It is an example of a product which demands large scale integration (for cost and size reduction) combined with a carrier frequency in the low GHz range. The potential broad spread of such a product, in a typical office environment, requires a frequency allocation in the low GHz range, whereas its characteristic as a computer accessory sets a hard cost limit.

2. SYSTEM OVERVIEW

The wireless data modem transmits a net data rate of 16kBit/s. It must work with low bit error rate in an environment where multipath propagation and narrow band interference from computer hardware and other RF equipment (such as wireless phones) are present. For an experimental setup of the system, a carrier frequency of 2.44GHz has been allocated by the Swiss PTT. The bandwidth and effective radiated power is limited to 80MHz and 100mW respectively.

The system uses spread spectrum modulation for multiple access and interference suppression. The spread code is a Gold code with a length of $2^{10}-1$ and a chip rate of 16.368Mchip/s. Thus, a system gain of 30dB is achieved. The receiver uses multiple IF strips and demodulators fed with time delayed copies of the spreading code. With appropriate synchronisation, not only the direct path signal can be received and processed, but also echos with various time delays from indirect propagations paths.

Simplified block diagrams of the transmitter and the receiver are shown in Fig. 1 (Ref. 1). A CMOS gate array containing the multi channel IF, demodulator and synchronisation section has already been realised (Ref. 2).

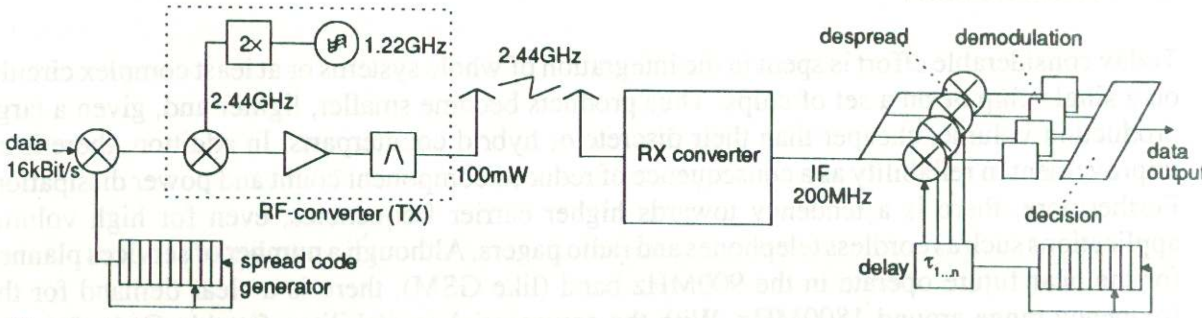


Figure 1: *Simplified block diagram of spread spectrum wireless data modem without sync circuits (Ref. 1)*

3. TRANSMITTER SPECIFICATIONS

Beside the general specifications (suppression of spurious emissions, low power consumption, size and cost) the utilisation of the spread spectrum technique implies some special requirements that are worth mentioning.

- The dispersion of the transmitted signal in a frequency band 1000 times larger than for direct BPSK modulation requires a carrier suppression of at least 30dB below the total power, if the unwanted carrier is to remain below the resulting spectral comb.

- The levelling of the signals of different transmitters, which all use the same carrier frequency but different codes, requires an output power control facility on the transmitter side. A range of 20dB at a maximum power of +20dBm is thought to be sufficient.

A frequency doubler for the carrier frequency shall be included on the chip. Beside the simplification of the application, frequency doubling with a push pull circuit is a typical application which fully exploits GaAs-IC technology: It requires only active components, and makes use of the tracking of the FETs on a chip, which is usually not available with discrete semiconductors. In addition, the frequency doubler may be too complex to realise with discrete components.

4. REALISATION

4.1. Description of the foundry process

The foundry process used (Triquint QED/A) is a 1μm gatelength enhancement/depletion process, providing MESFETs with three different threshold voltages (+0.15, -0.6 and -2V) and an average transition frequency (f_T, extrinsic definition) of 10GHz. Two levels of wiring metalisation (one usable as airbridge), NiCr thinfilm resistors and MIM capacitors are available.

4.2. Chip architecture

A systematic separation of functions suitable for efficient integration and those requiring too much chip area was performed. As a result, the final amplifier matching network and the carrier oscillator have to be realised off chip. The only exceptions are small on chip power supply blocking capacitors. They allow relaxed specifications for the placement of external blocking capacitors and simplify packaging and bonding. A block diagram is shown in Fig. 2.

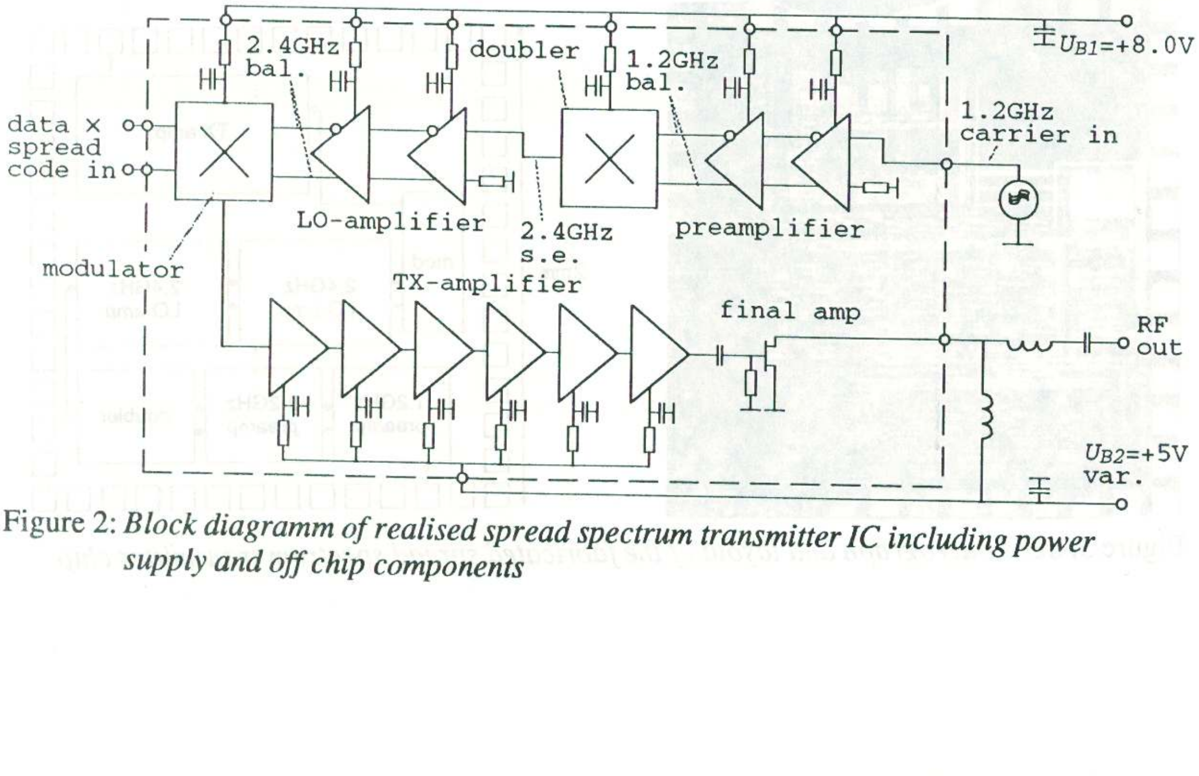


Figure 2: *Block diagramm of realised spread spectrum transmitter IC including power supply and off chip components*

4.3. Circuit design

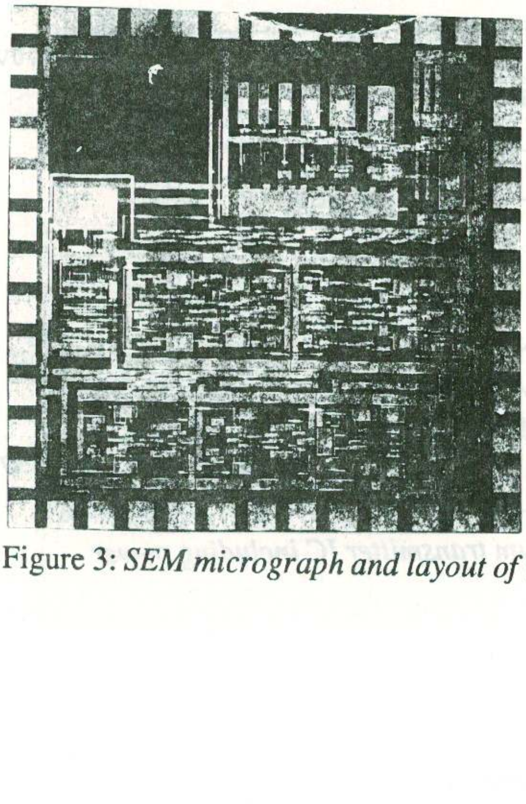
The 1.2GHz-preamplifier, frequency doubler, 2.4GHz-LO-amplifier and modulator are fully differential. Balanced wiring provides a convenient method to drive the frequency doubler and the doubly balanced modulator, and, in addition, enables a separation of bias and signal paths. This provides high power supply rejection through a constant and signal level independent current source.

Cascodes are used as amplifiers and current sources. The active loads of the differential stages are configured to give an inductive behaviour (Ref. 3). They improve the gain at the operating frequency, provide well defined DC-levels at the output nodes through the resistive bias (R in Fig. 1, Ref. 3) and enable the use of enhancement devices as loads (conventional active loads must be floating and have their source and gate connectors tied together, a topology which is not practical with enhancement devices). On the other hand, low frequency and DC gain is strongly reduced, which attenuates 1/f-noise and bias offsets, and prevents low frequency instability through excessive gain. The loads of the 2.4GHz stages (doubler, LO-amplifier, modulator and TX-amplifier) are tuned to give a significant attenuation at the carrier subharmonic at 1.2GHz.

The transmitter amplifier is the only section to use single ended circuitry. It consists of six common source stages (Fig. 2) with increasing width and active-inductive loads biased at half the supply voltage. Thus, the gain of the TX amplifier can be varied over a wide range by the supply voltage, while maintaining an equal voltage distribution over the amplifying (common source) and load FETs. The final amplifier is an open drain FET with a total gate width of 800µm biased at I_{dss}, carrying a current of 35mA at a drain voltage of 5V.

4.4. Layout

The layout for the differential stages is kept as symmetrical as possible. A metal strip at ground potential, which serves as the bottom plate of a small bias decoupling capacitor, is placed on each side of the stages to prevent unsymmetric sidegating. The modulator is built from interlaced multi-finger FETs which averages out FET variations as far as possible. An SEM micrograph and the layout is shown in Fig.3. The large rectangles visible on the photo are power supply blocking and interstage coupling capacitors.



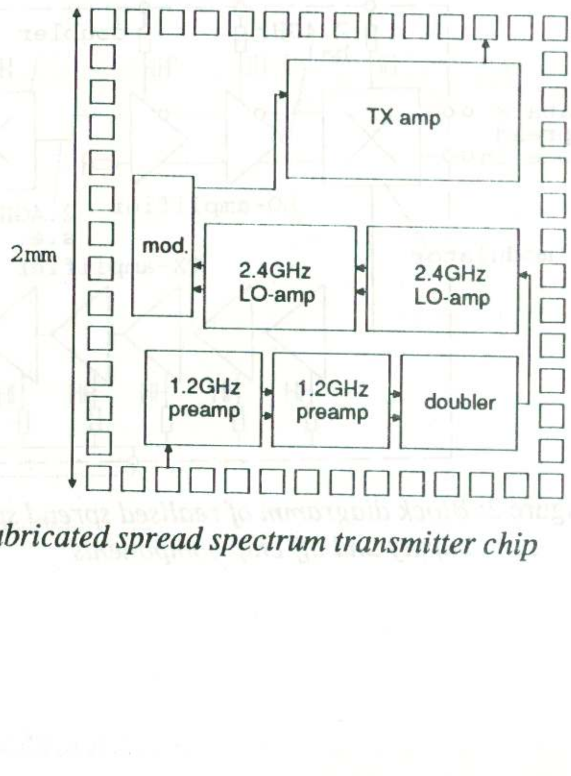


Figure 3: *SEM micrograph and layout of the fabricated spread spectrum transmitter chip*

5. RESULTS

5.1. General

Two wafers containing a total of 80 circuits have been fabricated. Six devices (three from each wafer) were packaged in standard 8I/O microwave packages and thorougly characterised. 20 unpackaged chips, mounted on a small glass plate, were tested on a wafer prober. All measurements were carried out with a bias-T and a 50Ω-load at the transmitter output (no output matching for maximum output power was used). An M-code generator (code length 1023, chip rate 16Mchip/s) with differential outputs at the modulation ports and a 0.2V/1.22GHz sine oscillator at the carrier input port were connected. 25 of the total of 26 devices were operational. The output spectrum of a typical device is shown in Fig. 4 (span 200kHz) and Fig. 5 (span 50MHz). In Fig. 4, the remaining carrier, suppressed by approx. 6dB, can be seen slightly left of the centre line.

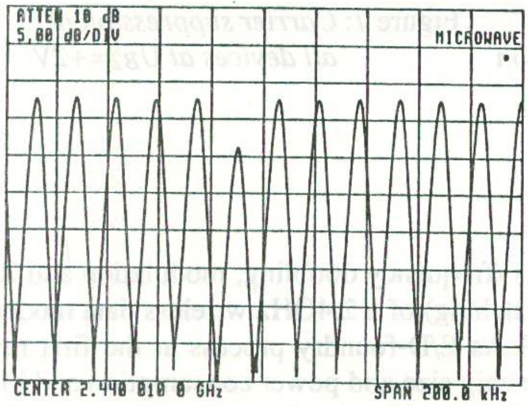


Figure 4: *Measured output spectrum of spread spectrum TX modulated with spread code alone (span 0.2MHz)*

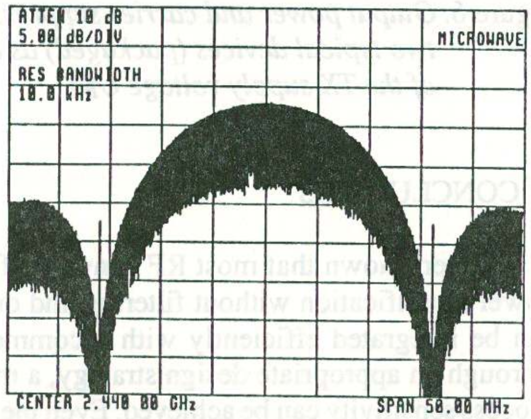


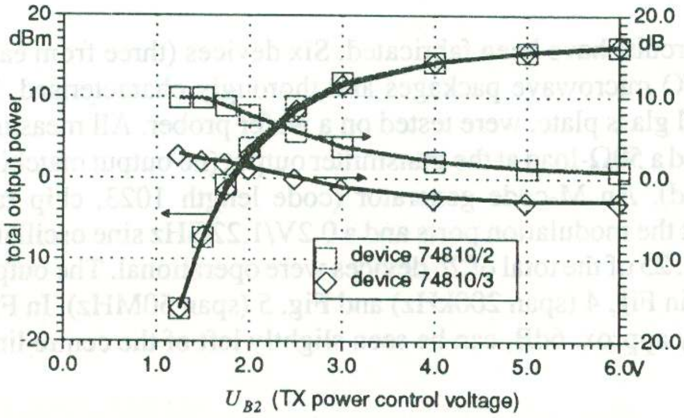
Figure 5: *Measured output spectrum of spread spectrum TX modulated with spread code alone (span 50MHz)*

5.2. Power consumption and output power

The power consumption at +8/+5V supply (maximum output power) of the six packaged devices was measured to be in the 1.0 to 1.2W range, including approx. 35mA of current through the bias-T of the output stage. The associated maximum unmatched output power was between 30 and 50mW. A power control range of >30dB was achieved (s. Fig.6).

5.3. Carrier suppression

The measured carrier suppression shows a strong chip to chip variation and a pronounced output power dependence. Fig. 6 shows the output power and the carrier suppression of two typical packaged devices as a function of the TX supply voltage U_{B2}. Carrier suppression becomes worse with increasing output power. An unintended feedback from the final amplifier to the modulator through improper grounding is suspected to be the cause. The unpackaged chips suffer from insufficient cooling if operated at full output power (U_{B2}=5V). As a result, the comparison of carrier suppression was performed at U_{B2}=+2V for all devices. However, they principally show the same behaviour as the packaged devices. In addition, a strong influence of the unequal chip heating, caused by the variable dissipation of the TX amplifier, on the carrier suppression is observed. Fig. 7 shows the distribution of the carrier suppression of all functional devices at U_{B2}=+2V. 23 of the 25 functional devices provide sufficient carrier suppression at the selected output power.



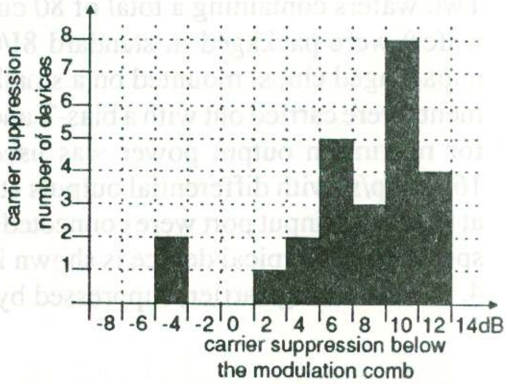


Figure 6. *Output power and carrier suppression of two typical devices (packaged) as a function of the TX supply voltage U_{B2}*

Figure 7: *Carrier suppression of all devices at U_{B2}=+2V*

6. CONCLUSIONS

It has been shown that most RF converter functions (frequency doubling, modulation and RF power amplification without filtering and output matching) of a 2.4GHz wireless data modem can be integrated efficiently with a commercial GaAs E/D-foundry process at the first run. Through an appropriate design strategy, a moderate chip size and power consumption and low process sensitivity can be achieved. Even the demanding specification for the carrier suppression could principally be fullfilled with high yield using differential circuitry and an interlaced modulator layout. However, unbalanced chip heating and parasitic feedback from the power amplifier at high power levels deteriorate the carrier suppression by more than 10dB. In a next design cycle, the high power and the symmetric doubler and modulator section will be integrated on separate chips.

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