Power Efficiencies of Linear Transmitter Architectures for Handportable, Satellite Communications

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linear transmitter architectures

The provision of a linear transmit section within a mobile transceiver facilitates the use of arbitrarily amplitude-and -phase modulated signaling, potentially resulting in flexible and spectrally efficient communication. This paper highlights some relevant narrowband, linear transmitter architectures appropriate to satellite handportable and mobile transceivers, and attempts to quantify their relative merits in terms of power efficiency and complexity.

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POWER EFFICIENCIES OF LINEAR TRANSMITTER ARCHITECTURES FOR HANDPORTABLE, SATELLITE COMMUNICATIONS

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The provision of a linear transmit section within a mobile transceiver facilitates the use of arbitrarily amplitude-and-phase modulated signalling, potentially resulting in flexible and spectrally efficient communication. This paper highlights some relevant narrowband, linear transmitter architectures appropriate to satellite handportable and mobile transceivers, and attempts to quantify their relative merits in terms of power efficiency and complexity.

Introduction

The power consumption budget is a dominant factor in the design of mobile transceivers; a useful battery life must be achieved with a practical battery capacity. This implies low power consumption in stand-by and efficient operation during active periods. For transceivers with transmit powers of many Watts, the power consumption of the transmit RF hardware generally dominates the power budget; this is especially true when linear operation is required. However, with the signal processing complexity of communications systems continuously increasing and the use of lower transmit powers for satellite transceivers, current linear transmitter architectures may already be sufficiently power efficient for hand-held and mobile applications.

The perceived advantages of multimode terminals, e.g. NADC/Satellite, GSM/TACS/Satellite, requires transceivers to have at least band switching capability if not truly wideband operation; hand-off between terrestrial and satellite systems requires further flexibility. Suitable transmitter architectures must therefore be capable of such operation. The choice of architecture is further complicated if the linearly-modulated RF channel is wider than a few tens of kHz.

Power Consumption Estimation

The theoretical power efficiencies of various classes of amplifier are well documented [1]. The linearity of classes A, AB, B & C can be improved with a variety of feedback and feedforward correction schemes, whilst high-efficiency switching amplifiers (class D, E etc.) can be used to generate linear modulation using RF synthesis. At low transmit powers ($\leq$1W), however, a significant proportion of the transmit power consumption is attributable to the transmit signal processing (the combination of the system baseband processing and any linearisation signal processing).

Most linear transmitter architectures are based around basic signal processing elements available as discrete devices. The current technology of such devices is a good starting point for estimating the power efficiency/consumption of various transmitter architectures. In this analysis, the best device for a purpose has been chosen regardless of process technology (Bipolar, CMOS, BiCMOS & GaAs); for some components the more exotic processes appear to be the enabling technology. Whilst this approach yields the most power efficient transmitter for a particular architecture, it takes no account of cost, integration problems or supply voltage strategy (although most devices surveyed were for

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either a single +3v or +5v supply). Where no ideally specified device exists, the power consumption has been extrapolated from similar devices. DSP power consumption has been estimated by firstly estimating the processing load in million-instructions-per-second (Mips), and then scaling according to the current technology in 16-bit, fixed-point DSP devices, i.e. 1.4mA Mips^{-1} @3v (4.2mW Mips^{-1}) (courtesy of *Texas Instruments*). RF power amplifier (PA) efficiencies are based on measured data from a 900MHz class C device with a peak efficiency of 52% which decreases approximately linearly to 0% at zero output. This is reasonably representative of a number of medium power ($\leq$1W) MMICs currently available.

The following sections summarise the performance of three suitable narrowband, linear transmitter architectures. Consideration is given to all transmitter components after and including linearisation DSP and data canversion.

Cartesian Loop

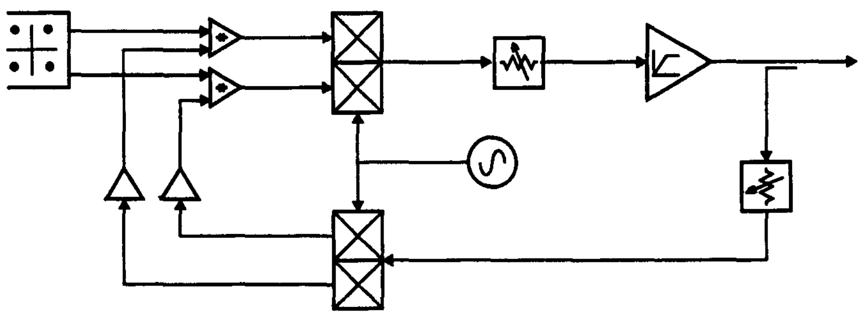

Figure 1: Basic Cartesian Loop transmitter

Figure 1 shows a block diagram of a Cartesian Feedback transmitter architecture. The baseband in-phase and quadrature representation of the modulation is applied to the low-pass differential amplifiers which serve to drive the RF chain so as to minimise the difference between the input modulation and the downconverted feedback modulation. Assuming stability, a linear frequency translation and power amplification is achieved. The variable attenuators are used to effect power control. A more detailed discussion of such a transmitter is given in [2]. In terms of power consumption, the main devices are the PA, the quadrature modulator/demodulator, the wideband baseband pre-amps/integrator and the synthesizer; the power consumption of the baseband pre-amps is directly related to the bandwidth of the RF channel.

Figures 3 and 4 indicate the estimated power consumption and efficiency of the Cartesian Loop. A two-tones test has been used as the modulation for ease of analysis and because it exercises the full envelope range of the transmitter. It is important to note that the RF power device is being operated in a quasi-linear fashion and consequently suffers a decrease in efficiency as the envelope level decreases. At peak output (two tones test) the upper limit of efficiency (i.e. with channel bandwidths of 5kHz or less) for a 1W transmitter is $\approx$35%; 750mW, 500mW and 250mW transmitters give efficiencies of 33%, 28% and 21% respectively. These efficiencies will be reduced by approximately 0.03% kHz^{-1} as channel bandwidth is increased, mainly due to the increased gain-bandwidth product (GBWP) required for the baseband preamps and integrators. Once output powers of below 300mW are required, the efficiency falls off rapidly due to dominance of the signal processing power consumption. This is confirmed by figure 4.

Adaptive Baseband Predistortion

Adaptive Baseband Predistortion (ABP) is a modulation feedback linearisation technique similar to the Cartesian Loop. The key difference is that instead of the continuous analogue feedback employed in the Cartesian Loop, ABP uses DSP at baseband to adaptively estimate the RF PA nonlinearity and simultaneously predistort the modulation to correct for the nonlinearity. The use of discontinuous feedback relaxes the stability constraints experienced with the Cartesian Loop. A more detailed discussion is given in [3]. In power consumption terms, the pre-amps and integrators of the Cartesian Loop are replaced by DSP, with stereo A/D conversion (≥10 bits resolution) also required in the feedback path. The DSP processing load is high; predistorting the modulation significantly increases the signal bandwidth and therefore also increases the sampling rate. A sample TMS320C30 based implementation required approximately (1.5 × channel bandwidth in kHz)Mips, based on an assumed linear adaption algorithm operating at $\frac{1}{6}$th of the predistorter rate.

Figures 5 and 6 summarise ABP power consumption and efficiency. It can be seen that with narrowband channels the power efficiency is similar to that of the Cartesian Loop. However, as channel bandwidth is increased the power consumed by the DSP and the data conversion increases drastically and has a severe effect on efficiency.

Combined Analogue Locked-Loop Universal Modulator

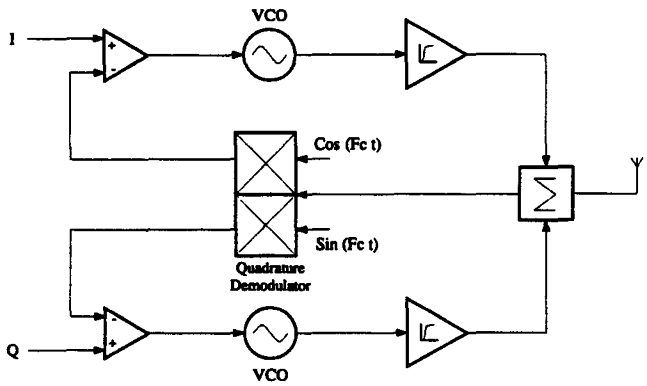

Figure 2: Basic CALLUM architecture

This technique (figure 2) was proposed in [4] as an efficient method of generating an arbitrarily modulated carrier by vectorially combining two constant-envelope signals (RF synthesis). Because the signals involved are constant envelope they may be amplified with highly efficient switching amplifiers; if they are then combined in a power efficient manner the resultant RF section of the transmitter will have excellent power efficiency which is maintained at all envelope levels. In terms of power consumption, the dominant components in a CALLUM transmitter are the PAs and combiner, the wideband preamps and differential amplifiers, the two VCOs and the downconverter.

Figures 7 and 8 summarise the power consumption and efficiency of the technique. Where the power consumption of the PA/combiner unit has been included, the efficiency stated for this unit is assumed to remain constant regardless of output envelope level. Naturally, the PA/combiner efficiency affects the transmitter efficiency directly, with increases in channel bandwidth again reducing the efficiency due to the need for wider bandwidth preamps and loop filters.

Conclusions

Three possible architectures suitable for hand-held, linear transmitters have been shown and estimations made of their power efficiency/consumption for output powers of one Watt or less. Such power levels are typical of those proposed for hand-held, mobile satellite terminals. The Cartesian Loop and Adaptive Baseband Predistortion (ABP) both operate the RF power device in a quasi-linear fashion and are thus suitable for linearising class C devices. CALLUM is an RF synthesis technique and can thus employ switching classes of RF amplifier, giving the technique a much higher theoretical efficiency.

Of the three techniques, the Cartesian Loop is perhaps the simplest; the linearisation signal processing consists of basic analogue building blocks which are suitable for high levels of integration. The power consumption of the signal processing depends upon the required channel bandwidth, but is estimated to be of the order of 400mW for a 30kHz channel. In terms of power consumption, ABP and the Cartesian Loop are similar for channel bandwidths less than 20kHz; for channels wider than this the high DSP requirements of ABP increase the power consumption drastically. Even with channels of less than 20kHz, the DSP requirements are likely to make the cost of such an architecture significantly higher than the Cartesian Loop. Hence ABP's stability with channels wider than those possible with the Cartesian Loop is achieved at the expense of a severe increase in power consumption.

Successful implementation of an RF synthesis system requires three main blocks:- a power efficient, RF, vector combiner; high efficiency amplifiers capable of covering the bands of interest; and an accurate method of generating the constant envelope signals from the linearly modulated input. With a PA/combiner efficiency of 50%, the CALLUM technique gives similar transmitter efficiencies at peak output to the Cartesian Loop; even with a PA/combiner efficiency of 80%, CALLUM only gives real efficiency advantages with output powers of greater than 500mW. Thus, the theoretical advantages of RF synthesis are diminished by the low output powers required for hand-held transmitters.

In a TDMA system, the importance of the transmitter efficiency is further reduced. In each of the three architectures shown here, the majority of the transmitter may be powered down between transmit frames. For example, a 1W Cartesian Loop transmitter operating with a 12.5% duty cycle may consume as little as 250mW; this is likely to be less than the power consumed in the rest of the transceiver (vocoder, coding etc.).

In conclusion, these results give a marker for what is currently achievable with the three architectures discussed. The power efficiency has been shown to be sufficient to enable the use of linear modulation at the low output powers produced by compact, hand-held transceivers. Whilst future component technology developments, such as the use of 1v logic and low power data conversion, will vary the results presented here, the general trends will still be valid.

Acknowledgements

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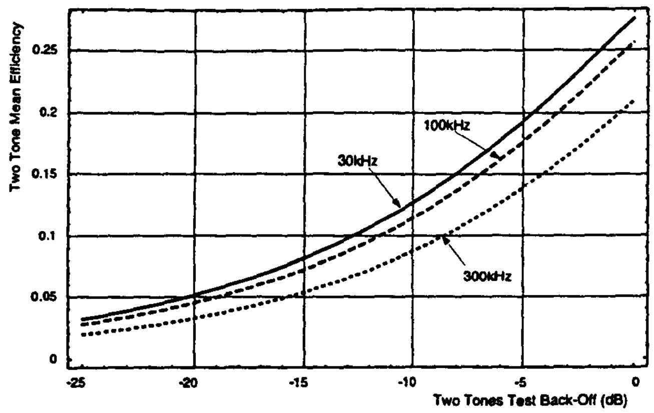

Figure 3: Two tones mean efficiency vs back-off for a 500mW Cartesian Loop transmitter with 30kHz, 100kHz and 300kHz channels

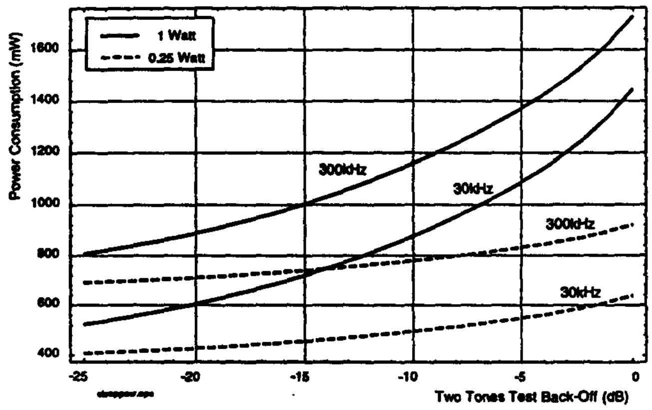

Figure 4: Two tones mean power consumption vs back-off for 1W and 250mW Cartesian Loop transmitters

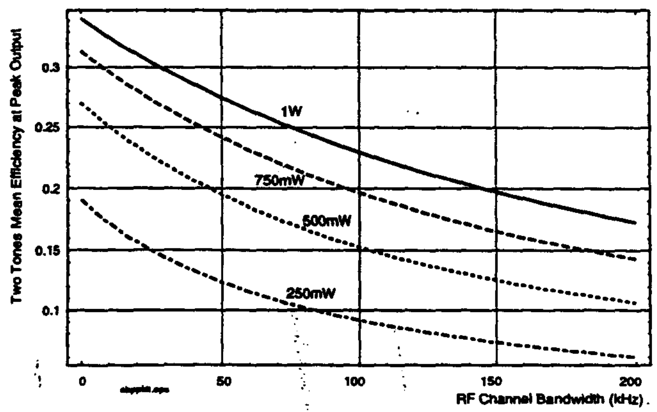

Figure 5: Peak two tones mean efficiency vs channel bandwidth for an Adaptive Baseband Predistortion transmitter

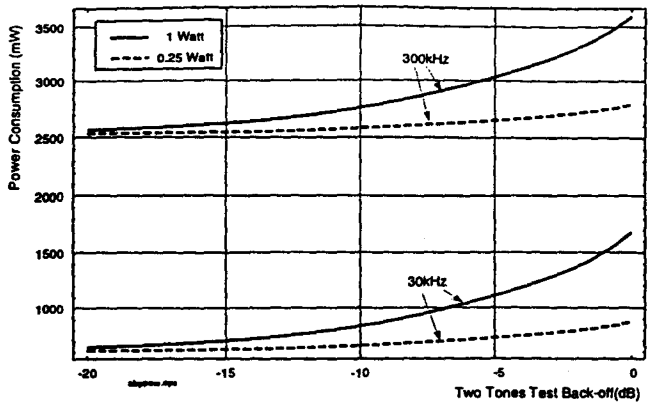

Figure 6: Two tones mean power consumption vs back-off for 1W and 250mW Adaptive Baseband Predistortion transmitters

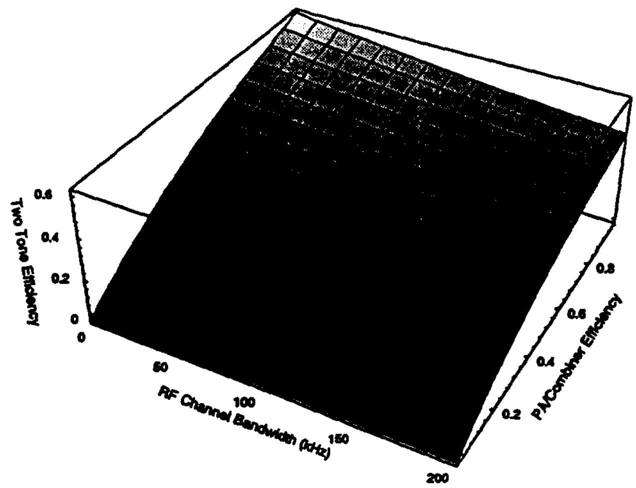

Figure 7: Two tones mean efficiency vs channel bandwidth and PA/combiner efficiency for a 1W CALLUM transmitter

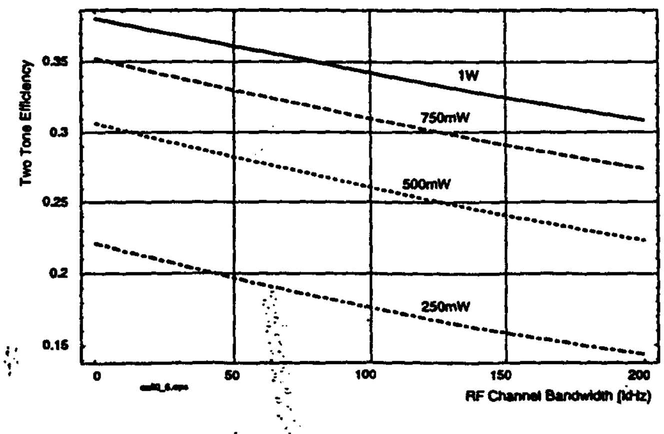

Figure 8: Two tones mean efficiency for 1W, 750mW, 500mW and 250mW CALLUM transmitters with a PA/combiner efficiency of 50%