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TITLE: **POWER-DRAIN CONSIDERATIONS FOR FULL TIME AND SLEEP MODE RADIO RECEIVERS**

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BACKGROUND

There is concern that a continuously-operating receiver may use more battery capacity than is acceptable. One alternative is a "**sleep mode**" where the receiver is "**awakened**" by a timing and sampling schedule or by the presence of carrier. If it is awakened by signal present, enough of the radio to know that a signal is there must operate continuously.

Before accepting that the receiver should include a sleep mode and a particular awakening method, it is necessary to know the unavoidable power drain for a data output and a carrier detecting (only) receiver. It is possible that keeping power-drain low is more feasible than accepting the system performance loss from receivers that only listen part-time.

CONCLUSION

It is believed that the estimated or better receive mode power drain may be attained with sufficient effort. These levels are sufficiently low, much less than a flashlight bulb, that no effort should be invested in methods to provide a logical sleep mode for the signal path of the Station receiver.

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BACKGROUND

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Radio Design Considerations

The main concern is the first mixer and local oscillator (LO). With diode ring mixers (most commonly used), the LO power required is +7 dBm or more. References are presented for microwave active mixers requiring levels of 0 dBm or less LO power.

A further concern should be the exposure of the first mixer to out-of-band signals at high levels. Part of minimizing the LO power is reducing the required level for the overload point, and this depends upon system design and in part upon bandlimiting between the antenna and mixer.

Another concern is minimizing the first intermediate frequency in the receiver for reduced cost and power drain which also depends in part upon the selectivity in a front end bandpass filter.

The solutions to these problems may be different for the Station and Access-point. This contribution looks only at the Station radio.

Output Signal Processing

It is assumed that much of the signal processing sleeps until a signal is present. This function is not considered in detail in this paper, though it is also an important matter.

RADIO TECHNOLOGY REFERENCES

References deal with specific frequencies up to 12 GHz, however they are selected on relevance and usefulness of reported technology.

With modern design, the criteria of usefulness is whether the circuit function can be modeled and simulated in analysis programs, and one of the more difficult circuits in this respect is the active mixer which has non-linear aspects. It has become impractical to design commercially by experiment and iteration.

Active Mixers and Required Local Oscillator Power

"A GaAs MESFET Mixer with Very Low Intermodulation"[1]

The circuit described used the FET in resistance mode resulting in a bilateral circuit (the circuit will work in both directions--up and down converting). The resistance is shunted across the transmission path and value modulated by the LO. Comparisons are relative to diode ring mixers. The Author says:

"*This paper has shown that mixers based on the resistance of a GaAs MESFET channel have significant advantages in noise, intermodulation, and power output capabilities over those based on a pumped Schottky-barrier diode junction. Such mixers are easy to design and adjust, and have characteristics which make them entirely practical for use in low-noise receivers.*"

The experimental work is done at a signal frequency of 10.3 GHz and an LO at 8.8 GHz. One of the objectives was a passband width of 300 MHz.

In Figures 6, 7 and 8, data is shown for conversion loss, P_{IM2} and P_{IM3} as a function of LO power from 0 to +10 dBm and a few different gate bias levels. The conversion loss is 8 dB at 0 dBm and 9.5 dB at -2 dBm LO power. The results take into account the losses in strip-line filter used to separate the frequencies at the drain.

In Table I, the Author gives a "Mixer Comparison" of a diode, resistive MESFET and active MESFET types. The resistive type shows large advantage on second and third order overload criteria, but is inferior on noise figure and conversion gain to the active MESFET.

Comment: This mixer draws no power on its own. With high drive, an output level of near +10 dBm is obtained. The noise figure is good enough for a receiver front end. It is interesting to consider this mixer used alternately in each direction with nothing but a higher level of LO while transmitting. Performance would be somewhat better than given at lower frequencies.

"Nonlinear Analysis of GaAs MESFET Amplifiers, Mixers, and Distributed Amplifiers..."[2]

Using the analysis method described, the Author says *"The final solution shows that an IF output of 45.37 μW results from a signal input of 7.846 μW with an LO power of 0.6147 mW."*

The confirming experiment was done at a SIG frequency of 8.2 GHz and LO at 7.0 GHz. In Figure 7, plots of gain and dc drain current vs. gate-source bias are shown for P_{LO} of -2 dBm. The drain current ranges from 15-50 ma at V_{ds} of 3 Volts.

"Analysis and Design of MESFET Mixers"[3]

The modeling method and parameters are given, and then backed with experimental data on a 12 GHz single-transistor circuit with an 11 GHz LO. In Figure 9, plots are shown for conversion gain and SSB noise-figure vs. LO power. Usable performance (NF=7 dB, Gain=5 dB) is obtained down to 0 dBm LO power.

"Double Balanced Mixers Using Active and Passive Techniques"[4]

"Abstract--A variety of double balanced mixers, employing dual-gate FET's or diodes as the mixing non-linearities, have been fabricated using planar monolithic technology. The mixer topologies, which use active balancing methods, eliminate the need for large suspended substrate structures, thus minimizing circuit area and facilitating integration. These unique approaches also eliminate IF extraction problems and combine the best performance characteristics of FET's and diodes."

This is a particularly interesting paper addressing many of the issues in producing an MMIC. In particular, it deals with an active balun taking up far less space than a transmission line version; and it considers dual-gate FETs not usually considered.

Unfortunately, the design goal was a broadband range of 2-18 GHz. It is of considerable technology interest in eliminating or minimizing tuned circuits and resonant filters, but not on minimizing power drain.

"Dual-gate FET mixers can be analyzed with the aid of a non-linear simulator such as microwave HARMONICA, LIBRA, or Microwave SPICE."

"GHz-Band Monolithic Modem IC's"[5]

For use in a 1 GHz carrier, 200 Mb/s QPSK burst modems; the authors describe MMIC circuits for a double balanced mixer, 90° phase shifter and on-off carrier switch all using high f_t bipolar transistors. The circuits for both up and down conversion are shown.

The double balanced mixer is a 4-quadrant linear multiplier which uses -10 to -20 dBm of LO power while delivering up to -15 to -25 dBm output in up-conversion.

The 90° phase shifter is a differential RC network with active baluns and adjustable capacitors derived from biased diodes.

The carrier switch is important because it is impractical to turn oscillators on and off very quickly. The active switch described provides a 60 dB down off-level.

"Balanced FET Up-Converter for 6 GHz, 64-QAM Radio"[6]

The described dual-FET, balanced mixer up-converts 70 MHz to 6 GHz with high linearity and output levels up to 14 dBm with an LO power of 18 dBm. The LO output leakage is reported as 19 dB below signal level and better than diode rings. With the FETs biased at pinch-off, the LO is reported to drive the drain current to 40 mA at 9 Volts.

The circuit used is diagrammed and well described.

"Quasi-optical HEMT and MESFET Self-Oscillating Mixers"[7]

"In this paper, we present quasi-optical receivers that employ a coupled slot antenna and a balanced HEMT or MESFET self-oscillating mixer. ... an isotropic conversion gain of 4.5 dB is achieved ... the new circuits are more compatible with FET-based MMIC technology since no diodes are used." say the Authors in the introductory paragraph.

An interesting feature of this work is the use of the resonant properties of the antenna to provide necessary filtering functions. The model described used two FETs in a balanced circuit.

The experimental work was done at a SIG frequency of 11.87 GHz and IF of 1.6-1.7 GHz. For the MESFET receiver, the lowest noise figure observed was 9 dB and better for HEMT.

Voltage Controlled Oscillators

"Uniplanar MMICs and Their Applications"[8]

Their are two particularly interesting features in this paper: 1) uniplanar design on a single surface of Gallium Arsenide and the choice of 6.5 GHz to implement a voltage controlled oscillator for a 26.5 GHz MMIC. There is not much circuit description though pictures of the layout of the various circuit elements are shown.

"Two ouput terminals are required for the VCO because the output power must be supplied to the ... frequency doubler and the frequency divider. The VCO is a FET oscillator with a series feedback configuration. A source-drain shorted FET was used as a varactor diode."

"In the VCO design, the transmission line approach was employed since it provided more accuracy than the lumped element approach."

"As the control voltage varied from 0 to -7 Volts, the oscillation frequency varied from 5.9 to 6.5 GHz with a main power output of more than 8 dBm, as shown in Figure 10."

Quadrature Phase Shifters

These circuits typically derive two outputs with 90° phase difference which is relatively easy over a narrowband with trimming, and quite difficult over wider bands or where a tolerance of 10-20% in components is inevitable. One approach is described in Ref. 5.

"Monolithic RC All-Pass Networks with Constant Phase Difference Outputs"[9]

"Abstract--All-pass network techniques have made it possible to realize very small monolithic lumped active phase shifters with decade bandwidths, high yield, and relative phase stability, even when the device parameters vary ±20%. We have successfully demonstrated fully monolithic first-order networks (at 250 MHz) and second-order networks (at 4 GHz)."

This is one of very few useful papers on this subject in the context of IC realization. The Authors have done it very well.

Passive Bandpass Filters and Resonators

Radio design often includes tradeoffs between filtering and more complex circuits to avoid the need to filter. Passive filters are unsurpassed for minimizing power drain, but not for cost or size. Progress in high Q ceramic based filters started with the need for duplexers in hand-held cellular telephones, and has now progressed to a state of refinement hardly imaginable at the beginning.

"Novel Dielectric Waveguide Components--Microwave Applications of New Ceramic Materials"[10]

This paper is an expert and valuable summary of the field it covers. Improvements in the microwave loss and temperature stability of dielectric constant, as reported in this paper, make possible astonishingly small complex function components. Dr. Konishi says:

"Thus far, high dielectric constant ceramic materials have been used to make coaxial resonators ... in filter applications. This paper shows several dielectric-waveguide components utilizing appropriate metallized surface structures on dielectric ceramics. Using magnetic walls, easily realized with ceramics, several dielectric components of a type quite different from conventional hollow waveguide components are realized. Multistage BPF's with coaxial resonators in waveguide are also shown. Components similar to earlier dielectric waveguide components are made smaller by taking the image half-section."

Materials are listed with Q range 5,000-35,000, dielectric constants 20-90, and temperature coefficients at or within a few ppm of zero/°C.

There is an explanation of the magnetic wall--an open ended waveguide that does not radiate.

Implementation details are shown for coupling, tuning and transition to microstrip lines by shaping of the metallization patterns on the ceramic.

A number of filter designs of known and ingenious mechanical configuration are shown along with test data.

In Figure 38, an open end silver metal surface resonator 4 mm thick, 6.5 mm wide and of variable length up to 15 mm is shown. At 10 mm long, the Q is 634 and the resonant frequency is 2.3 GHz.

Mathematical methods for calculating resonator properties are given.

RADIO MODEL AND DESIGN CONSIDERATIONS

The signal frequency is 2.4 GHz. The receiver block diagram assumed contains the following functions:

1) Low noise rf amplifier at signal frequency (optional)
2) 1st mixer--signal to IF downconverter
3) 1st LO with buffer amplifier
4) 1st IF amplifier and bandpass filter
5) 2nd mixer--dual I and Q
6) 2nd LO and buffer amplifier
7) Baseband filters and amplifiers--dual I and Q
8) Baseband signal processor

Simplified block diagrams are shown in Figures 1 and 2 on the last page.

The transmitter block diagram is similar except traversing the functions in the reverse direction. The local oscillators for transmitting and receiving are then common.

The radio is a linear up-down converter for a pair of baseband signals in phase quadrature.

High/Low Side 1st Local Oscillator Injection

High side injection is better from the point of view of spurious response rejection. All of the economic factors are on low-side injection which is commonplace in UHF and microwave radio design. If the IF is low, this choice is much less important.

Selection of 1st Intermediate Frequency

For a 1.7-2.5 GHz radio receiver, the first IF frequency might be from 140-600 MHz. A 5.9 GHz might not use any higher frequencies. The selection of the first IF is somewhat subjective choices even though the performance is predictable.

Similar considerations apply to transmitters where there is up-conversion. Spurious radiation occurs at frequencies where spurious responses occur in receivers.

Mainly for the purpose of estimating current drain, the choice of a 140 MHz 1st IF frequency is suggested as default starting point. This puts current drain and cost of implementation ahead of spurious considerations. Minimization of local oscillator radiation will be aided by use of a single balanced (two transistor) active mixer.

Gain/Power Supply Efficiency

Narrowband linear Class A amplifiers may have output power that is limited to 10-20% of the power used, however class B amplifiers might get to 40-50%. Circuits running at 5 volts will be significantly less power efficient than those at 9 volts.

Video amplifiers cannot be used at frequencies higher than a few MHz for power efficient designs. Bandpass amplifiers produce the most gain per milliwatt of power supply. The current that must be consumed is proportional to the setting of the maximum signal level output capability of the amplifier.

RECEIVER POWER-DRAIN BUDGET

The following is a skilled guess by this contributor considering the references given above and other factors for the minimum receiver analog portion power budget with a 5 V power supply at 2.45 GHz:

1)	Signal frequency amplifier	Not used
2)	1st mixer	10
3)	1st LO and buffer amp	20
4)	1st IF amp	20
5)	2nd mixers	20
6)	2nd mixer LO	20
7)	2nd video amp	20
	power drain--milliwatts:	110
		22 mA @ 5 V

If there were to be only a signal presence detector, the drain of 5, 6 and 7 might be replaced by circuits drawing only 30 mW for a new total of 80 mW. It is not easy to decide whether this estimate is optimistic or pessimistic. The basis for this estimate is the relationship between power drain, gain and signal levels which bear an attainable relationship with each other.

A considerable design and laboratory effort would be required to obtain an estimate with a better level of dependability.

CONCLUSION

It is believed that the estimated or better receive mode power drain may be attained with sufficient effort. These levels are sufficiently low, that no effort should be invested in methods to provide a logical sleep mode for the signal path of the Station receiver.

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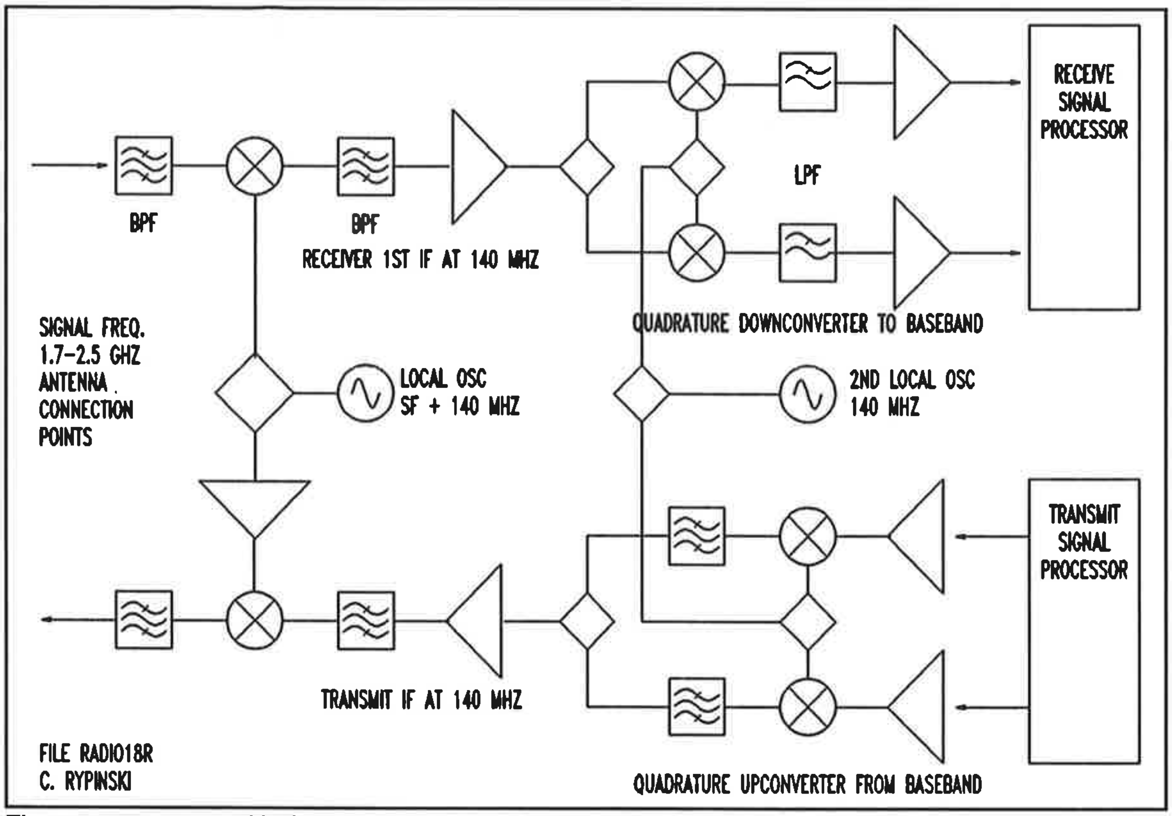

Figure 1. Up/down converter block diagram for QAM

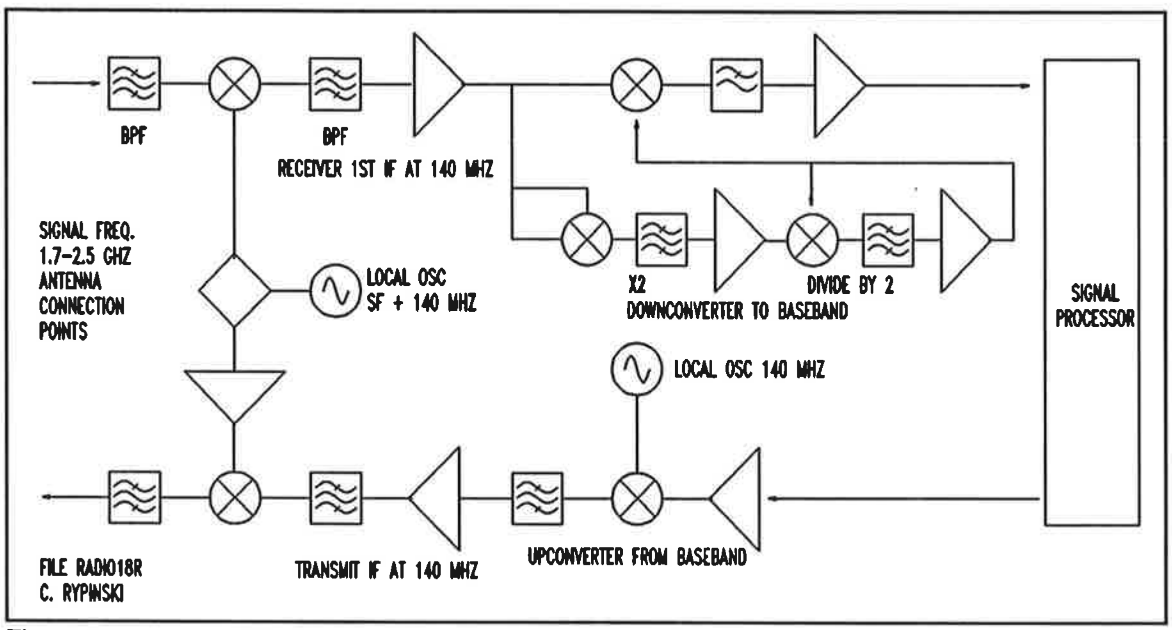

Figure 2. Up/down converter block diagram for PSK