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Lanwave Technology, Inc.

White Paper

A Second Generation *CD/SS*™ Chip set

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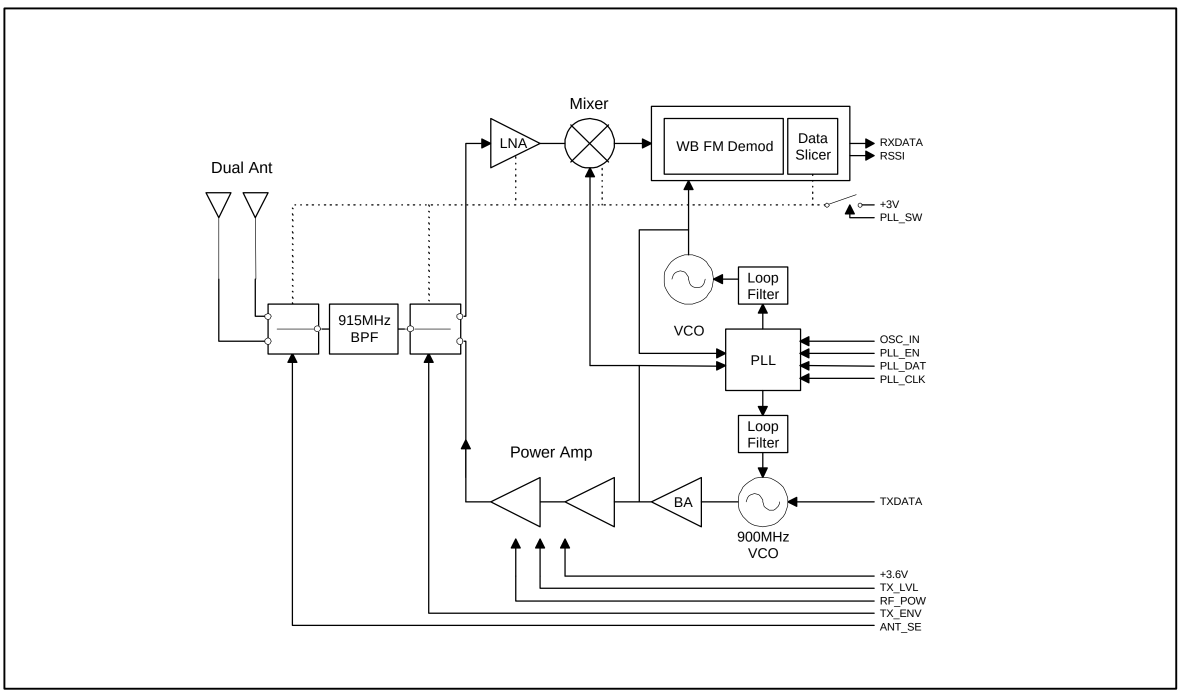
System Cost-Performance Advantages
with the SATURN-II Product Family

The original SATURN DSP family uses full rate CD/SS™ color codes so there is few flexibility in designing a matching wide band RF module. The SATURN-II has made several upgrades in the DSP algorithm and thereby making available a range of cost performance options in its RF design. Furthermore, the data rate and CD/SS code compression function allow for a full rate 64 kbps uncompressed PCM bit stream to be sent without the ADPCM codec, reducing cost while leaving room for future software upgrades in the MCU. A synchronous CD/SS (S-CD/SS) mode is supported for 4-GFSK type RF modules to carry an orthogonal channel, which can be non-spreaded to send 384 kbps full duplex data in a low power mode for MPEG applications. This technical note will discuss these topics. More details may be found in the associated Lanwave document as included.

1. General block diagram of a GFSK wide band RF design.
2. Reduce IF bandwidth with Fractional Chip Rate (AN-1, AN-10, AN-22).
3. High processing gain CD/SS™ color codes (AN-8).
4. Direct voice sampling and transfer (AN-21).
5. Diversity registers (AN-9, AN-11, AN-12, AN-13, AN-15, AN-16).
6. Interfacing SATURN-II with Bluetooth, 2.4GHz DECT and UHF/ISM RF transceiver chips and modules. (AN-25, AN-26, AN-27.)

1. A generalized, frequency independent, architecture of a wide band RF design



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1A. The above diagram depicts a 2-stage conversion, frequency shift keying architecture. The first stage is the conversion from the RF frequency to an intermediate frequency (IF) stage. The second stage converts the IF signal, after filtering and discrimination, to base band data. In the cost conscious consumer electronics market, these two blocks serve very different economic needs.

i. RF to IF conversion block serves to adapt for individual country's telecomm spectrum regulations, disassociate the software dependent PLL block from constant product change. As a result different designs tailored for different markets can be developed in a rapid cycle time.

ii. Discrete components in this block are more conducive to technological change, and ride down the economy of scale (cost curve) at a higher rate than the rest of the RF sub system. For example, 2.4 and 5.7 GHz LNA transistors today are still at multiple time of their projected maturity cost. This is due to the need to return on initial fixed investment by the component manufacturers.

Assuming a balanced need for ROI (Return on Investment) between the component supplier with the need by OEM manufacturers to develop cost conscious, fast cycle products, the RF-to-IF conversion block will naturally exist. However, it will be kept down to a minimum on BOM proportion. The figure of engineering merit is its ***total ownership cost***, which includes manufacturing, testing, QA and design change cost over time. The Lanwave open architecture keeps this block separate from both base band and software to allow for a rapid adaptation cycle at the least BOM and time exposure. This benefit is preserved in the new SATURN-II family.

From time-to-time, there exist opportunities in the marketplace to use single chip RF transceivers, or to take advantage of subsidized components to meet space critical needs. For example, transceivers developed for the DECT, HomeRF and Bluetooth standards by PC and cellular phone companies are highly integrated. Lanwave recognizes this need and the SATURN-II architecture has been modified accordingly. This will be explained in the last section and associated Technical Notes. However, even in such cases the RF requirement and its underlying semiconductor economics generally do not provide for a single chip solution when high transmission power is required. As such RF engineering knowledge will continue to be important in this business, and particularly crucial in the competitive consumer electronics industry.

1B. The IF-to-baseband block captures all the engineering to recover a digital signal from the EM wave. Since digital recovery may tolerate a higher quantization noise in amplitude, the main function of this block is therefore to expend the least to recovering the bits within the tolerance limit of the DSP engine operating at the base band.

i. It disassociate radio frequency dependency from software architecture.

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ii. High fidelity recovery of the IF signal, which could be folded with image noise from the first mixer, to within the digitizing limit.
iii. Channel isolation within the conversation spectrum.
iv. Frequency diversity with agility (time diversity).

Typical of consumer electronics design, the elements popularly used in this block are generally amortized from prior consumer applications such as those from the AM/FM radio, UHF TV receiver, hi-fi stereo filters and the latest is DECT radio chips. Since the market price on these components are well known and narrowly spread amongst suppliers, cost is almost identical for every manufacturer. The figure of merit here is mainly performance. This is captured fully in the Receiver's Sensitivity Equation. This block is the most pertinent to the competitive analysis of a radio design. The rest of this Technical Note will address each term in the equation and how the second generation SATURN-II DSP chips help to offer a competitive edge.

Receiver sensitivity, S, is expressed at ambient temperature by the following equation:

$$S\ (dBm) = -174(dB) + NF(dB) + 10\log(BW) - G_p + (E_b/N_o)$$

where
- NF = receiver's noise figure.
- BW = IF bandwidth
- Gp = Processing gain from base band DSP
- Eb/No = bit energy to noise ratio, 11.0 dB for 10^-3 BER in non-coherent modulation schemes including FSK, MSK and GMSK.[1]

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[1] In FCC Public Notice #54797 describing the measurement procedure for compliance testing under Part 15.247 on spread spectrum radio, the <u>ideal</u> non-coherent receiver's Eb/No is calculated from:

Pe = (1/2) e ^ (-1/2 (S/N))

Where, Pe = probability of error, or BER
S/N = Eb/No in this particular case.

Based on this equation, Eb/No is calculated and listed below for reference:

BER	Eb/No	
====	======	
10E6	14.2dB	
10E5	13.4dB	
10E4	12.3dB	
10E3	11.0dB	
10E2	8.9dB	
3.2 x 10E2	7.4dB	(average 1 chip error per color symbol.)
1.25 x 10E1	4.4dB	(average 4 chip error per color symbol.)

1.25 x 10E1 or one per eight chip error, when assumed to be Gaussian, is roughly the limit to maintaining a high quality voice link under the SATURN-II DSP architecture.

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1C. The transmitter block could be considered as the third element in a wide band radio design. But because of the simplicity of direct frequency modulation using varactor element, this block is relatively homogeneous. The major variations are:

i. Power amplifier - standard design at less than 100mW (20dBm) is the most typical among home consumer products using 3.6V batteries. [2]
ii. Non-linear up conversion using amplified harmonics is sometimes used to reduce cost. This is a cost reduction strategy and does not affect base band analysis.
iii. Meeting FCC out-of-band and spurious requirements base on spectrum filters and transmit pulse shaping.
iv. Matching and de-coupling to minimize on PCB noise.

Continue with the old tradition, the SATURN-II allows non-linear PA to be used, making room for cost reduction. The major design attention is the pulse shaping, or so called the Gaussian filter. It is a low order, low pass filter aligned with the chip rate and should be designed to introduce a minimum amount of inter symbol (i.e. chip), and adjacent channel interference. And particular to the architecture of the SATURN-II, this pulse shaping filter should be design with a minimum amount of group delay distortion for the DSP algorithm to achieve a superior processing gain.

***SATURN-II* Improvements:**

The new DSP engine in the SATURN-II family is targeted to optimize the radio cost-performance considerations stated above. ***If the old SATURN family architecture were described as designed from the side of the microcontroller, then the new SATURN-II can be viewed as designed from the side of the radio and EM wave.***

All existing software developed for the old SATURN are able to run without change in the SATURN-II family, thereby protecting software investments. And the new functions are available in new registers for subsequent product and feature upgrades.

Design guidelines in 1A and 1C have been described. Most of the cost and performance is affected by 1B, the IF-to-base band conversion block. There are four functional improvements in the SATURN-II facilitating competitiveness:

IMPROVEMENT #1: Increase RF sensitivity by reducing IF channel bandwidth. (Fractional Chip Rate mode, AN-1, AN-10, AN-22.)

[2] The operating region of a power transistor is therefore about 3.0V. At 50% PA efficiency, and driving into a 50ohm antenna load, the EM power emission in an ideal VSWR is: $0.5*V^2/R = 100mW$. Higher power design generally incurs a discrete jump in cost.

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In the sensitivity equation, the background thermal noise sets the lower bound at -174dB. The cascaded noise figure, the NF term, is determined by component selection and is largely limited by cost, availability and vendor considerations. The last term, Eb/No is intrinsic to the wireless modulation scheme. All these terms are unaffected by the SATURN-II architecture. The two remaining terms are (1) channel bandwidth, and (2) processing gain. Both were improved in the SATURN-II DSP circuit and microcode to offer system competitive advantage.

The SATURN-classic architecture adopted a 32 chips per symbol, 8-symbol alphabet in its CD/SS implementation. In a nominal 19.2 Mhz system using a TDD/FDD link layer architecture, these parameters translate into an IF chip rate of 1.365 million chips per second. This is equivalent to a maximum chip frequency of 682 Khz. Henceforth, using GMSK modulation index of 0.5[3], the required channel bandwidth is:

$$\text{IF BW} = 2 * (\text{Fmax} + \text{Fdev}) = 2* (682 + 341) = 2.048 \text{ MHz}$$

Using the fractional chip rate mode (details in AN-1, AN-10 & AN-22) the chips per symbol in SATURN-II is reduced to one-half (J-code), one-third (T-code) .. to a minimum of one-sixth (W-code) for the FSK radio. 8-symbol alphabet is kept to preserve software compatibility. Processing Gain is maximized with phase encoding (VPSK) which is a Pulse Width Modulation (PWM) technique on horizontally position chips. The result is a reduced IF bandwidth requirement as tabulated below. A reduced IF bandwidth from the 2.048 MHz old design will result in upto 7dB of sensitivity performance as governed by the difference in the term: 10log(BW).

Code Rate	IF bandwidth	RF Sensitivity Improvement
X-code (Full rate)	2.048 Mhz	0
J-code (1/2)	1.024 Mhz	+ 3 dB
T-code (1/3)	682 Khz	+ 4.5 dB
U-code (1/4)	512 Khz	+ 6.0 dB
V-code (1/5)	410 Khz	+ 6.8 dB

If the old SATURN RF module was able to achieve a -92dBm sensitivity, then the SATURN-II chip will improve the sensitivity to -95dBm under J-code, -96.5 dBm under T-code, -98 dBm under U-code classes etc.. The narrower bandwidth support more channel options and in addition, may result in up to 100% range improvement under open field conditions. The next section will address the processing gain subject.

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[3] GMSK index of 0.5 generates the least amount of inter-symbol and adjacent channel interference. Lower index can be used in GFSK and the analysis in this paper remains the same.

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IMPROVEMENT #2: Increasing processing gain by color phase compensation. (For details please see Technical Note AN-8.)

The second item in the equation subject to improvement is processing gain. Theoretical gain is a direct result of the linear algebra in CD/SS code selection. In practicality, this is limited by the processing accuracy of the internal DSP algorithms in color splitting, filtering and decisions. In a 32-chip, 8-color alphabet the maximum theoretical gain is 15.1 dB, should all color codes chosen were exactly orthogonal.[4] However, practical limitations generally reduce this processing gain figure by 2, and sometimes 4 dB.

In the SATURN-II family the DSP algorithm had been improved with a more precise phase accuracy. The chips in each symbol are no longer addressed vertically as are in the SATURN-classic, but are addressed and process as variable length horizontal pulses. This PWM algorithm has reduced the processing gain residual lost. The sensitivity improvement is in between 2 to 4 dB and are more pronounced at lower rate codes.

The DX2 engine has implemented a higher resolution over the VX2, further approaching the ideal asymptote. Comparing with the VX in normal mode, the improvement is 2dB in VX2 and 4dB in DX2. Thereafter gain improvement widens. And the gap in between VX2 and DX2 increases. This is summarized below. It lists processing gain after color phase compensation. The gain metrics are depicted in dB:

	SATURN		**SATURN-II**	
Code Rate	**VX**	**DX**	**VX2**	**DX2**
X-code (Full rate)	**~11**	**~13 dB**	**~13**	**>14 dB**
J-code (1/2)	N.A.	**~12 dB**	**~11**	**>13 dB**
T-code (1/3)	N.A.	**~11 dB**	N.A.	**~12 dB**
U-code (1/4)	N.A.	N.A.	N.A.	**~11 dB**

If the FCC Part 15.247(e) testing method is used, and the RF module design suffers from inherent noise (such as LO phase noise, non-linear modulation product, group delay, sub-optimal filtering etc..) the measured PG will differ. However, it is very reasonable to expect the L9002DX2 system to passing the FCC test with U-codes while the VX2 will pass with J-codes and above.

Processing gain performance which does not fully show up under the SATURN classic, will now provide improved sensitivity under the SATURN-II. (*predicated on good circuit design that do not take away too much phase margin.* [5])

[4] Code orthogonality implies zero mutual interference. This is analogues to the choice of primary colors (RED, GREEN and BLUE) in a color separation process. These colors are exactly orthogonal as are in the ideal CD/SS codes. The old SATURN implementation generally leaves a residual mutual interference of 2 to 4 dB, reducing the processing gain from the ideal 15.1 dB. This is from DSP quantization error.

[5] The importance of controlling phase distortion can be best illustrated in an example. If the Group Delay GDR variation is 300ns across the IF band, say in a 19.2 Mhz design having a phase margin of 360ns, the

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Due to the steep curve of Eb/No with FSK modulation, the sensitivity difference from a 1.25x 10E1 noise level (the limit on high quality voice transmission) to a 1x 10E3 noise level (the comparable limit in a narrow band phone system) is only about 6.6 dB, so the improvement from the PG term on non-coherent modulation is comparatively small. The main benefit from DSP gain, however, is that it allows for a narrower bandwidth code to be used while still meeting FCC Part 15.247(e), thereby enabling IMPROVEMENT #1 to be fully applied, making up to 6 dB additional sensitivity under the 1/4 rate code.

IMPROVEMENT #3: Cost reduction with direct voice sampling. (AN-21.)

From its linear clocking architecture, the SATURN-II using a double rate Mclk has twice the data bandwidth. This can be applied in conjunction with fractional codes to preserve, or still reduce, the IF bandwidth requirement. Using double rate clock will enable the uncompressed PCM voice at 64 kbps to be sent using the same RF module[6] and thereby eliminating the cost from the ADPCM codec chip.

In addition to BOM cost reduction, direct PCM transfer has the following additional advantages:

i. Allowing modem signal to go through as non-recursive PCM samples.
ii. Reduce any remaining audio echo by shortening TDD frame and cycle time.

More details are described in Technical Note AN-21.

IMPROVEMENT #4: Diversity registers (AN-9, AN-11, AN-12, AN-15, AN-16).

The ability to avoiding noise is the most potent form of RF improvement. The SATURN-II facilitates RF diversity by the following additional registers:

i. Space diversity: automatic antenna selection. (Details in AN-9).
ii. Frequency diversity: orthogonal hop set generator. (Details in AN-13, AN-15).

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net phase error will be shrunk to 60ns. Whereas when GDR is controlled to within 120ns, the net margin is 240ns or four times better. In the prior case a 1/4 size phase jitter will cause phase quantization error to occur at every high frequency chip transition. This by itself do not always generate a wrong color decision since the color symbols are inherently chosen to be immune from quite a few such phase errors. However, the GDR distortion is now taking away from the amount of external noise that can be otherwise tolerated. It has the effect of tilting the Eb/No curve to a more vertical position along the SNR at the sensitivity edge, which is where it really matters and could create the most amount of damage. On the contrary, amplitude distortions do not introduce the same systematic effect. The point here is to optimize on phase design in a CD/SS radio, and compromise on amplitude for phase resolution if needed.

[6] The RF PLL gap time is shorten by 50% under a double rate clock. The analog design should be fast enough for TDD direction switching down to 250us from 470us.

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iii. Time diversity or agility: providing additional packet mode bandwidth in the acquisition burst frames, allowing effective packet burst under data mode operation. (Details are discussed in AN-16, AN-20.)

Effective diversity need to be built fundamentally into MCU software. The general Multiple Handset, Multiple Line (MLMH) software architecture is explained in Lanwave Technical Notes AN-11 and AN-12. A reasonable implementation in a consumer class microcontroller is within 4~6K size codes. And over 50% of these codes are identical and migratable from narrow band CT0, CT1 phones.

Summary:

Combining improvements 1 to 4, benefits of upgrading to SATURN-II are:

VX (X-code, 2Mhz BW) → DX2 (U-code, 550Khz BW)

Performance:	>6 dB. (2x distance, open fields.)
Cost:	Eliminate IF SAW filters if wider spacing is used. (up to $1.50 BOM).
	Eliminate ADPCM codec if 2x Mclk is used. (up to $2.50 BOM).
Agility:	More frequency hopping channels. (conjugate diversity.)
	More simultaneous multiple handsets supported. (up to 4 times.)

IMPROVEMENT #5: Interfacing SATURN-II to low cost RF chips and modules.

These will be explained in detail in AN-25 (Bluetooth RF chip), AN-26 (2.4GHz pseudo DECT RF transceivers, modules) and AN-27 (UHF/ISM RF transceiver.)

To obtain more information on CD/SS™ technology[7], please contact your local Lanwave representative or directly contact Lanwave at:

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