Eavesdropping On Mars – Part 2.

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Design Drivers For A X-Band Receiver?

In part 1 we estimated that a Martian satellite transmitting 20 watts would create a signal to noise ratio (SNR) of 34.1 dB / 1Hz on Earth assuming the use of two 3 meter dish antennas and at closest approach (78.9 Gm). Could a low cost receiver be designed to intercept these signals?

Prior to design, it is useful to identify a few key design drivers. For example, in weak signal environments, strong overload immunity will be relatively unimportant whereas achieving a low noise figure have high However, amateur radio enthusiasts do not have unlimited finance so costs are also important. Further, designs that require multiple tuning adjustments may require expensive test equipment and reducing or eliminating these may also be desirable.

Listing a few key drivers can be useful prior to defining specifications as this provides an objective method for selecting between various implementations. It is common to identify many candidate design

approaches that will all satisfy design objectives but some will better

match design drivers than others. Therefore listing some key design

drivers that identify what a designer is actually trying to achieve can be

useful.

Some key drivers include low noise noise figure (NF < 2 dB), reasonably

low cost, minimal tuning adjustments, use of modern high performance

SMD components, and simple construction. The project should also be

education and introduce readers to design concepts that will be useful in

other receiver design projects. These goals set a scene for general design

objectives, however can such receivers systems, consistent with these

design drivers be realised?

Determining Suitable Specification Targets

Having identified some key drivers, defining some specification targets is

appropriate. Since satellites orbiting Mars transmit signals between 8.4

and 8.5 GHz, this identifies a suitable RF frequency range. Also some

commercial receivers and "USB dongles" can process signals up to 1.3

GHz, setting an IF range from 1.2 to 1.3 GHz also seems sensible. Using

a moderately high IF also allows the use of very low cost, fixed image

rejection filters as opposed to tuned helical filters. This design decision is

compatible with previous key design drivers.

The receiver noise figure (NF) on FR4 substrates will not be as low as NF

~ 0.3 dB but setting NF < 2dB represents a reasonable goal. This is

consistent with low substrate cost and allows the use of inexpensive

silicon bipolar (SiGe) for RF LNA. For example, Infineon's

BFP840FESD device has FT ~ 85GHz and can be obtained from Digikey

(NZ) for as little as $8.13 total for 10 units. These have an advantage over

HEMT (FET) devices as they operate in 50 Ohm systems and avoid any

need for high Q matching networks. Typical NF~1dB at 8.5 GHz.

MMIC "gain blocks" have become increasingly popular and the LEE-39

from Minicircuits offers 13.5 dB power gain at 8.5 GHz, combined with a

low NF~2.4 dB. Its gain increases to 21 dB at 1.3 GHz so it is well suited

for second LNA application, post mixer gain and LO buffers. It is also

inexpensive at $US1.19 each for 20 units. If we assume the SiGe LNA1

followed by a MMIC LNA2, ~12 dB mixer loss and a MMIC post mixer

amplifier, conversion gain will be G_c ~ 15 + 13.5 − 12 + 21 = 37.5 dB.

The system will be locked to a 10 MHz reference, either a OCXO, GPS

system or lower cost TCXO. Signals from Mars may have significant

Doppler shifts so exceptional frequency stability may represent an

overkill. However we will specify that the X-band receiver will operate

from a 10 MHz reference, regardless of its source.

Finally, the supply voltage can be determined. Most SiGe devices only

require a few volts to operate, MMIC devices usually operate from a

supply of +8V with simple resistive bias and typical VCO modules only

require +5V. Consequently, the X-band receiver can be expected to

operate from a single +8V supply. This can be derived from a higher +12

V input using a simple linear regulator if required.

Specification Summary

RF Input Range	8.4 to 8.5 GHz
IF Output Range	1.2 to 1.3 GHz
Conversion Gain	37.5 dB, approximate
Reference Frequency	10 MHz
Supply Voltage	+8 V, internal regulation assumed

The current budget will now be estimated. The LEE-39 MMIC RF LNA2,

IF buffer and VCO buffer will each require 40 mA, the BFP840 LNA1

will operate at 10 mA, and VCO modules typically require 40 mA. These

devices will therefore consume 170 mA. Other frequency synthesis

components could consume up to 50 mA. The current budget will be

Supply Current   Less than 250 mA.

The first implementation will assume the use of an external IF receiver.

However this may be upgraded later to include a second down conversion

to dual channel audio (I + j Q), suitable for sound-cards. This will use

direct conversion based on the availability of RF to IQ demodulator IC

components and contain its own tunable frequency synthesis sub system

Component Selections and Preferred Suppliers

Many component suppliers offer free postage for orders over a given

price. It follows that best cost efficiencies infer that multiple suppliers

should be avoided. Digikey (NZ) and Minicircuits offer a comprehensive

range of inexpensive components suitable for X-band receivers and are

preferred.

Suitable components, based on modern device technologies include

SiGe bipolar   BFP840 from Infineon, supplied by Digikey (NZ)

MMIC gain block LEE-39 from Minicircuits

Image filters   BFCN-8450 (Minicircuits)

VCO modules   ROS-3730C (Minicircuits)

or CV055CC-3500-3700 (Digikey)

VCO filter   BFCN-7200 (Minicircuits, assumes doubler)

Schottky diodes   BAT-15-03W (Digikey)

Pre-scaler IC   SY82230u (/5, /3 from Digikey)

or SY8100EL33LZG (/4 from Digikey)

Synthesiser IC   IDT-674-01 (Integer-N from Digikey)

Phase Detector IC IDT-673-01, 74HC7046AD (Digikey)

These devices and reasonably modern and inexpensive.

PCB Substrate Selection

FR4 is not well suited for operation at X-band but it is inexpensive and

many external PCB manufacturers are extremely familiar with it.

Superior substrates may be selected later though, if cost competitive. A

general principle is to avoid any high Q structures on FR-4 as they will

perform poorly. Additionally, high impedances, such as those required by

HEMT input matching structures should be avoided. It is wise to use 50

Ohm interfaces everywhere.

When FR4 substrates are used at microwave frequencies, a 4-layer stack

is most common. The top layers for RF and RF ground are generally thin

(H = 0.3 mm) to minimise ground inductance. The inner layer is usually

1.0 mm and the lower substrate height is 0.3 mm. Layer 3 is used for supply and interconnections and the lowest layer is used as a final supply, chassis and RF ground.

In keeping with the cost reduction driver, two layer FR4 is preferred over four layer stacks. However the use of standard 1.6 mm substrates could result in significant ground inductance. It is useful to use some general "rules of thumb" at this stage. Despite geometries, track inductances, whether horizontal or as vertical vias do not differ greatly from 1 nH per mm. At f=8.5 GHz, this implies X = 53 Ohms per mm! Using a thinner PCB is therefore prudent. We will assume standard 0.6 mm. From these reasons, we anticipate that home made PCB substrates with track-pins is likely to be problematic.

Architectures

There is no such thing as an "optimal design" as any given implementation depends on how well it complies with the initial design drivers. Many architectures will satisfy a given set of specifications but not al design drivers! Optimal, in this sense, just means optimal compliance.

There are two suitable architectures for a single conversion superhet receiver. The first is based on a ½ frequency VCO feeding a "sub-harmonic mixer" or SHM. These often use two anti-parallel Schottky diodes with a high-pass input filter, low-pass output filter and band-pass LO filter. The second more conventional approach also uses a ½ frequency VCO followed by a frequency doubler. This allows familiar double balanced mixers (DBM) to be used.

The system diagram shown in Illustration 1 depicts a SHM

X-Band Receiver - SHM Version
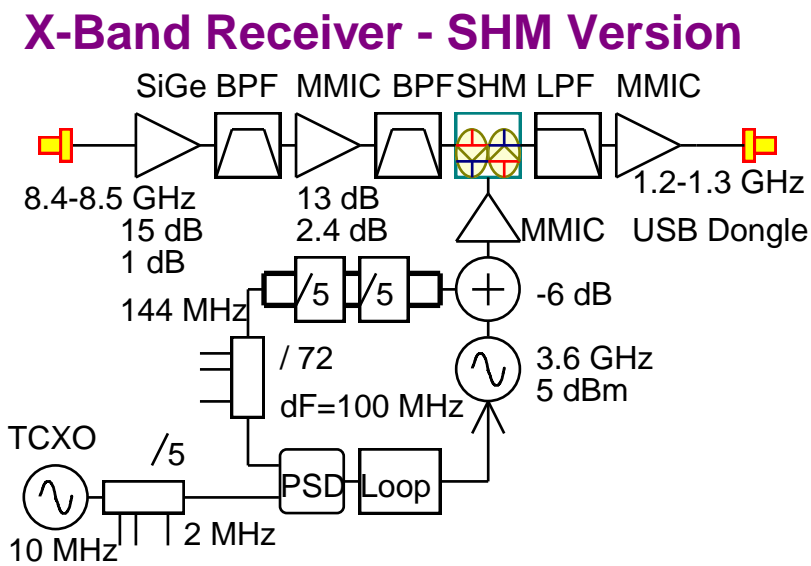
Illustration 1: Architecture based on a SHM

implementation.

Illustration 1 shows a simple down converter with two cascaded RF LNA, SHM and IF output LNA. The LO required for 8.4-8.5 GHz RF input and

1.2-1.3 GHz IF output is 3.6 GHz (twice this is 7.2 GHz). Many

inexpensive divider ICs will operate well at 3.6 GHz but those specified

for 7.2 GHz require a third supplier (potentially Hittite). The SHM

approach is convenient and allows /5 ICs (or /4) to be used, available

from Digikey (NZ). Using two dividers produces 144 MHz, easily

processed by an integer-N parallel load divider such as the IDT674-01.

This will be divided by 72 producing an output frequency at 2 MHz.

Given this high reference, a simple XOR gate might be suitable as a

phase sensitive detector (PSD). This will produce an output a 4 MHz with

a duty cycle proportional to the phase difference between XOR inputs and

can be filtered by a loop filter. Unfortunately this approach has a limited

frequency capture range and produces high reference side-band energy.

Consequently, standard phase-frequency detectors (PFD) are preferred.

Inexpensive examples include ICS673-01 (IDT), 74HC7046AD (NXP)

and HEF4046B (NXP).

The total division effective ratio is /2 /5 /5 = 50:1. Since the reference

frequencies is f = 2 MHz, the parallel divider will produce 100 MHz

integer frequency steps. In this concept, the IF receiver will provide fine

tuning inside this 100 MHz window.

The alternative approach is to use a standard double balanced mixer
(DBM) such as those provided by Minicircuits or an interesting SO-8
version from Digikey NZ. These require an LO at f=7.2 GHz, exceeding
the capability of dividers readily available from Digikey (NZ). The
solution is to retain the same VCO at f=3.6 GHz and follow this with a
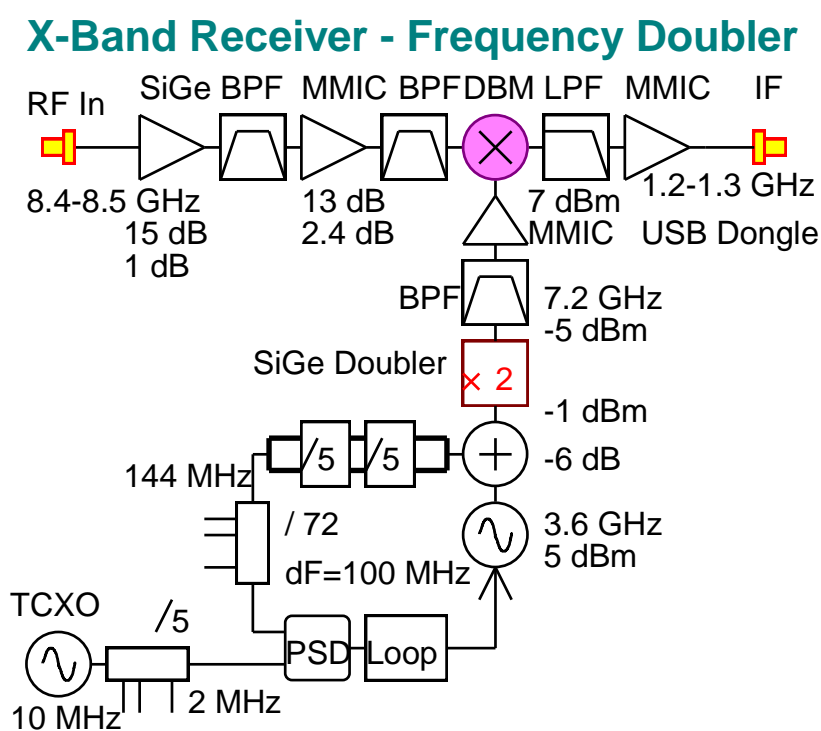frequency doubler as shown in Illustration 2.

X-Band Receiver - Frequency Doubler

Illustration 2:
Receiver based on LO frequency doubling

Both systems are functionally equivalent. The SHM approach requires
circuit level design for its mixer whilst the second requires circuit level
design for a frequency doubler. This later approach is slightly more
complex, requiring a 7.2 GHz LO MMIC amplifier.

For any design requirement there is usually several suitable options.

Some are great in some areas whereas alternatives may be great in others.

This is why it is a good discipline to start any design with a list of

"drivers" as this will help navigate architectural selection.

Summary

Hopefully this article provides illuminates design methodologies suitable

for X-band receiver architectures. These use a single down-conversion

followed by a 1.2-1.3 GHz IF. This can either be a commercial receiver,

microwave USB dongle or a subsequent second IF design using RF-IQ

down conversion to 2-channel audio suitable for a sound-card.

There is no "optimum design" except those that best comply with initial

design drivers. If different drivers are defined, alternative

implementations may become "optimum". It is wise to identify what

parameters matter most before engaging in any design as this discipline

will assist subsequent architectural selection.

The eventual two-stage superhet from Part 1 is shown in Illustration 3.

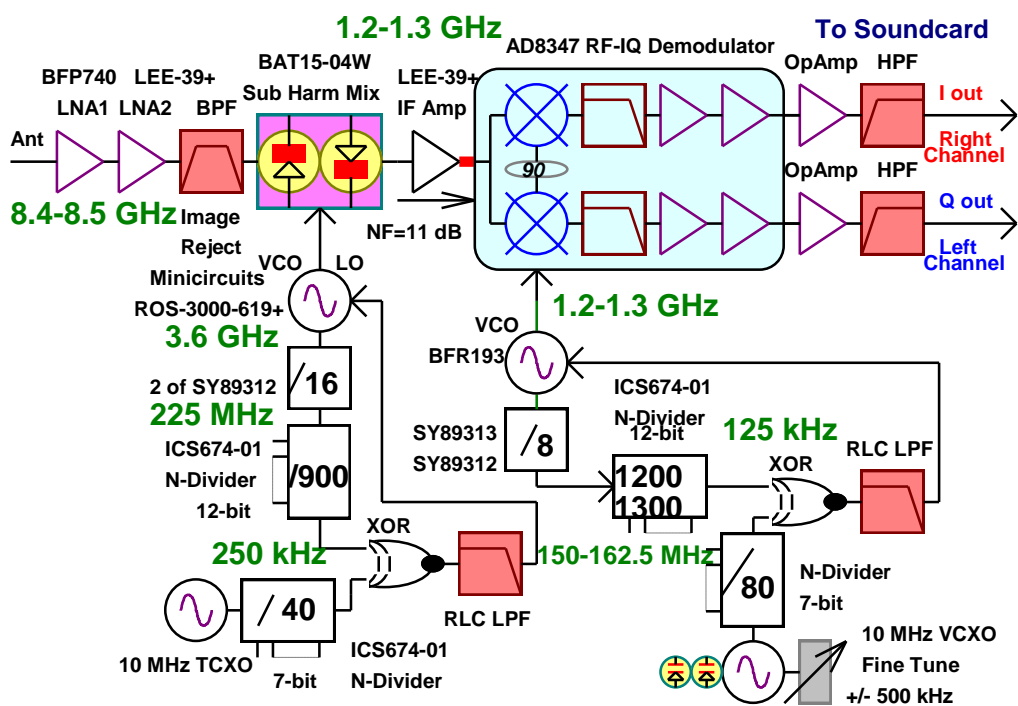# X-Band Receiver With Dual Channel Audio Outputs

Illustration 3: Complete system described in Part 1

The frequency plan shown in this article is slightly different to that described in this article. Also the XOR gate, used as a PSD will be replaced with a conventional PFD IC as this will avoid limited frequency capture range problems. These options show that many approaches are usually available, each performing similarly.

Future Articles

I plan to show circuit topologies for the RF frequency conversion stages in Part 3. These include SiGe bipolar LNA1, MMIC LNA 2, SHM and IF MMIC. Frequency synthesis circuits are planned for Part 4. These include LO MMIC, VCO module, two pre-scaler ICs, parallel N divider, phase

sensitive detector and loop filter. Since the topics relevant to each sub

system are very different, discussing each in separate articles is

appropriate.