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To: Broad Band Development Group

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Subject: **GGAO Receive Chain Component Configuration Considerations**

Purpose: To establish an optimum component configuration for GGAO's receive chain given the available RF components.

1. Current GGAO Configuration

After reviewing the current receiver operating configuration at GGAO and the specifications of the components used to construct the receiver chain, the configuration was found to be sub-optimal as argued in section 5. Figure 1 displays a diagram of the receiver chain for a single polarization. The device RF parameters relevant to this memo are printed in black below each component in the figure. The gain parameter is self-explanatory and the noise figure, *NF*, of the device is related to the noise temperature, T_n, by the IEEE standard definition:

$$T_n = 290\left(10^{\frac{NF}{10}} - 1\right) \tag{1}$$

The output power level at which the device enters saturation and deviates or compresses 1 dB from ideal linear operation is denoted P^o_{1db} in Figure 1. The input power level (P^i_{1dB}) which causes the device to enter saturation mode is determined by subtracting the gain (in dB) of the device from P^o_{1dB}.

The values printed in red at the output of each active component represent the power level at the input of the cascade (not the input of the individual component) that would result in P^o_{1dB} at the output of the given component. These values are obtained by simply taking the given component's P^o_{1dB} and subtracting from it the gains (in dB) of each stage preceding the device[1].

Having referred the P^o_{1dB} levels of each stage to the input of the cascade, the maximum input power limit (before the onset of saturation) of the cascade can be determined. The first stage to saturate, in the view of increasing the cascade input power level from minus infinity, imposes the limitation on the P^i_{1dB} level of the entire cascade. In observing the cascade P^i_{1dB} values (red font) in Figure 1, the fiber link saturates first, at an input level of P^i_{1dB} = *-79 dBm*. In section 3, P^i_{1dB} is compared to the effective system

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[1] The antenna and HPF, being passive devices, are not assigned P_{1dB} quantities so for the sake of this cascade analysis the compression point of passive devices are defined to be infinite. As is standard in RF cascade analysis, the noise figure of the passive devices are taken as the insertion loss of the component.

noise available at the input of the cascade to determine the saturation margin characteristic.

2. System Noise Temperature

The system noise temperature T_{sys} of the cascade is given by:

$$T_{sys} = T_{n1} + \frac{T_{n2}}{G_1} + \frac{T_{n3}}{G_1 G_2} + \ldots \qquad (2)$$

The T_{sys} quantity for the stages outlined in Figure 1 is calculated by applying equations (1) and (2) and in doing so T_{sys} is found to be *50K*[2]. Based on the effective system temperature and the operating bandwidth of the cascade (1-13 GHz), the thermal noise power at the front-end of the receiver is: $P_n = kT_{sys}B = k(50K)*(12GHz) = -81\ dBm$.

3. Saturation Margin

A useful metric in assessing the cascade's tolerance to RFI sources is saturation margin. The cascade's saturation margin Δ_s, in the context of this memo, is defined as the difference (in dB) between the input power compression level, P^i_{1dB}, and the front-end thermal noise power P_{ndB}:

$$\Delta_s = P^i_{1dB} - P_{ndB} \qquad (3)$$

Given that P^i_{1dB} = *-79 dBm* and P_{ndB} = *-81 dBm* for the cascade outlined in Figure 1, the saturation margin is Δ_s = *2 dB*. Given such a small amount of saturation margin, the cascade becomes very susceptible to saturation by RFI.

4. Front-End Input Power

Consider the source voltage signal, *s(t)*, that is picked up by the antenna. The total time-domain voltage signal, *sr(t)*, observed by the front-end of the receiver is the superposition of the thermal noise voltage of the front-end, *n(t)*, and *s(t)* :

$$s_r(t) = n(t) + s(t) \qquad (4)$$

Then assuming there is no correlation between *n(t)* and *s(t)*, the time average power, P_a, observed by the front-end is given by:

$$P_a = \left\langle |s_r(t)|^2 \right\rangle = \left\langle |n(t) + s(t)|^2 \right\rangle = \left\langle |n(t)|^2 \right\rangle + \left\langle |s(t)|^2 \right\rangle \qquad (5)$$

where the angle brackets are used to denote the time-average operator. The quantity $\left\langle |n(t)|^2 \right\rangle$ is the time-average noise power, which is equivalent to $kT_{sys}B$ and $\left\langle |s(t)|^2 \right\rangle$ is the

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[2]As we do not have an exact value for the ohmic losses in the antenna, the loss of the first stage in the cascade was selected such that the entire system had an effective noise temperature of ~50K; this is roughly what we expect for the system. The analysis can be easily recomputed in light of more definitive T_{sys} estimates.

time-average signal power. If $s(t)$ is decomposed into a Fourier series expansion, $\left\langle \left| s(t) \right|^2 \right\rangle$ is simply the sum of the time-average power in each Fourier component with amplitude $|a_n|$:

$$\left\langle \left| s(t) \right|^2 \right\rangle = \frac{1}{2} \sum_n \left| a_n \right|^2 \qquad (6)\,^3$$

Now that the time-average power in the received signal (equation 5) has been defined, the limit on the source's time-average power level can be developed.

5. Front-End Power Limit of Current Configuration

For simplicity $s(t)$ is considered to be a single frequency sinusoid[4] (i.e. only $n = 1$ harmonic of the Fourier series) or in practical terms a single RFI tone. As developed in section 1, the current configuration of the GGAO receiver enters the saturation mode when front-end power levels exceed $P^i_{1dB} = $ -79 dBm. So the question to pose is "How much time-average power can the source signal possess before the time-average power at the front-end is equal to P^i_{1dB}?" The time-average power limit on $s(t)$, P_{as1dB}, is determined by employing equation 5 and substituting $kT_{sys}B$ for $\left\langle \left| n(t) \right|^2 \right\rangle$ and $10^{\left(P^i_{1dB} - 30 \right)/10}$ for P_a, giving:

$$P_{ps1dB} = P_{as1dB} + 3$$
$$P_{as1dB} = 10 \log \left(10^{\left(P^i_{1dB} - 30 \right)/10} - kT_{sys}B \right) + 30 \qquad (7)$$

The peak power of the source sinusoidal signal, P_{ps1dB}, is related to the time-average power P_{as1dB} through equation (6):

$$\qquad (8)$$

Based on the values for P^i_{1dB}, T_{sys}, and B, **the time-average source/RFI power limit for the GGAO receiver in its current configuration is P_{as1dB} = -84 dBm**. Note that this level is below the thermal noise power (-81 dBm) of the front-end. In practice, however, there are routinely RFI components that far exceed this front-end thermal noise power level based on spectra observed at GGAO. For this reason it is believed that the GGAO receiver, in its current configuration, is operating in a nonlinear (saturated) mode.

6. Proposed Configuration and Performance

Figure 2 displays a proposed configuration of the GGAO receiver cascade designed to alleviate the small saturation margin of the cascade in Figure 1. Using equations 1-8 the performance parameters for the proposed cascade were calculated. A

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[3]The DC component of the series has been neglected as it is not within the pass-band of the receiver.

[4] For this analysis, the number of Fourier components considered is irrelevant as it is the time-average power in the total signal which is important. So we could consider 100 harmonics of the Fourier series of a complicated signal whose components sum up to a time average power level P_o or we can consider a single frequency signal whose time-average power is P_o.

comparison of these parameters for the current and proposed configuration is displayed in Table 1. **By simply removing the second 26 dB amplifier and adding a 12 dB amplifier at the output of the cascade significant improvement in the saturation margin** (to $\Delta_s = 28\ dB$) **and RFI handling** ($P_{as1dB} = -53\ dBm$) **of the cascade is gained at the cost of only** *2.7K increase in the system noise temperature* (*52.7 K*). Furthermore, with the receiver in this configuration, the thermal noise output of the cascade is *-40.6 dBm* which is the appropriate input level to the UDC per my conversation with Alan Rogers.

Lastly, the saturation margin of a receiver cascade is reduced when the P^o_{1dB} of a particular device in the cascade is not matched to the input P_{1dB} of the component following it. The P^o_{1dB} level of the cascade in Figure 1 is (*-25 dBm*) while that of Figure 2 is (*-13 dBm*). Because the P^o_{1dB} of the proposed cascade matches the input P_{1dB} of the UDC (*-12 dBm*) more closely than the P^o_{1dB} of the current driver, Figure 2 represents a better driver of the UDC.

	Current Configuration	Proposed Configuration
Noise Temperature (K)	50.05	52.67
Input Thermal Noise (dBm)	-80.81	-80.60
Output Thermal Noise (dBm)	-26.81	-40.59
Source Time-Average Power Limit (dBm)	-83.66	-53
Saturation Margin (dB)	1.8	27.6
Input 1dB Compression (dBm)	-79	-53
Output 1dB Compression (dBm)	-25	-13
Gain (dB)	54	40

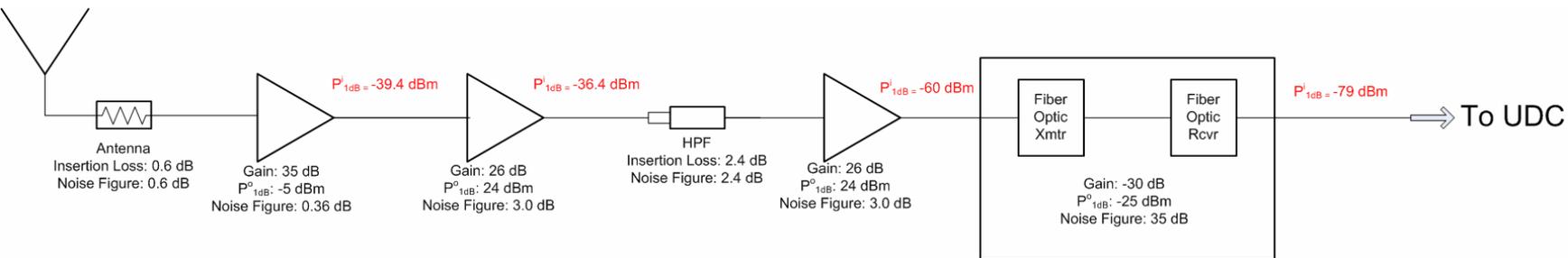Table 1: Comparison of current and proposed cascade performance parameters

Antenna
Insertion Loss: 0.6 dB
Noise Figure: 0.6 dB

P^i_{1dB} = -39.4 dBm

Gain: 35 dB
P^o_{1dB}: -5 dBm
Noise Figure: 0.36 dB

P^i_{1dB} = -36.4 dBm

Gain: 26 dB
P^o_{1dB}: 24 dBm
Noise Figure: 3.0 dB

HPF
Insertion Loss: 2.4 dB
Noise Figure: 2.4 dB

P^i_{1dB} = -60 dBm

Gain: 26 dB
P^o_{1dB}: 24 dBm
Noise Figure: 3.0 dB

Fiber Optic Xmtr

Fiber Optic Rcvr

Gain: -30 dB
P^o_{1dB}: -25 dBm
Noise Figure: 35 dB

P^i_{1dB} = -79 dBm

To UDC

Figure 1: Current Configuration of GGAO Receiver Cascade

Antenna
Insertion Loss: 0.6 dB
Noise Figure: 0.6 dB

P^i_{1dB} = -39.4 dBm

Gain: 35 dB
P^o_{1dB}: -5 dBm
Noise Figure: 0.36 dB

P^i_{1dB} = -36.4 dBm

Gain: 26 dB
P^o_{1dB}: 24 dBm
Noise Figure: 3.0 dB

HPF
Insertion Loss: 2.4 dB
Noise Figure: 2.4 dB

Fiber Optic Xmtr

Fiber Optic Rcvr

Gain: -30 dB
P^o_{1dB}: -25 dBm
Noise Figure: 35 dB

P^i_{1dB} = -53 dBm

Gain: 12 dB
P^o_{1dB}: 11 dBm
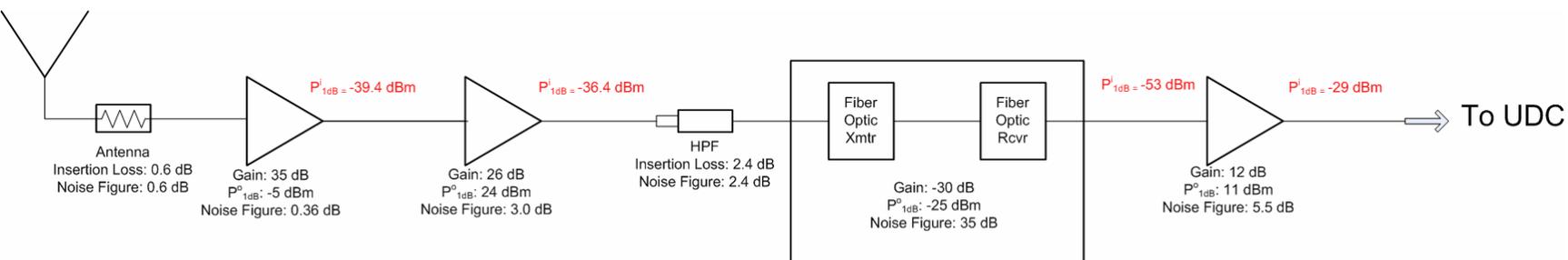Noise Figure: 5.5 dB

P^i_{1dB} = -29 dBm

To UDC

Figure 2: Proposed Configuration of GGAO Receiver Cascade