2007-2008 METEOR Instrumentation Platform Video Transmitter

Christopher J. Fisher

Project Background:

The METEOR Instrumentation Platform is an ongoing project with the goal of developing a mobile control station to be used in the launch of small satellites into low-Earth orbit. Some of the functions desired by the platform include rocket launch control, temperature and pressure measurement, GPS transmission for location and a continuous video feed to determine platform and rocket status.

Document Purpose:

The purpose of this document is to summarize the current video transmission system as of the end of Senior Design I during the 2007-2008 year. In this document the previous system analysis and design will be discussed followed by the modifications to the previous year's design in order to improve performance. Current circuit schematics and board layout will be included along with the intended test plan to measure and verify the performance of the circuits and ensure complete functionality.

System Analysis and Previous Design:

System Specifications for Video Transmitter:

The video format chosen previously was the NTSC format over the amateur radio 70cm band, center frequency of 439.25 MHz. This was chosen since the band and standards were already developed and could be utilized in order to minimize the amount of additional work on the teams. The choice of NTSC for the transmitting format was due to the choice of band as well the ability to easily receive the video data using a television. The analog format was also beneficial since the frequency range used is lower than most comparable digital formats in which case a lower frequency allows for a lower transmitted power to achieve the same received power. This can be seen through Frii's Transmission equation which relates the transmitted power, P_T, to the received power, P_R, in an antenna system, shown in Equation 1.

$$\frac{P_R}{P_T} = G_T G_R \left(\frac{\lambda}{2\pi R}\right)^2 PLF \qquad [1]$$

The values in Equation 1 include the transmitting antenna gain, G_T, receiving antenna gain, G_R, the freespace wavelength of the transmitted signal, λ, the distance between antennas, R, and the polarization loss factor, PLF, which is a measure of power lost due to mismatch in antenna polarization. The dependency of frequency is in the wavelength which is $\lambda = \frac{c}{f}$. Additionally, the power requirement of the transmitted signal was to be greater than 1W, ideally 5W, with a transmittable range of 500km, approximately 310 miles.

Video Transmitter:

To meet the requirement of NTSC format, the digital cameras chosen to be implemented with the control board were selected such that NTSC was an available output format. To accommodate the intended frequency band the MAX2370 Quadrature Transmitter was selected due to its available output RF frequency range of 410-500 MHz. The MAX2370 is a complete transmitter package including a baseband to IF modulator, IF to RF modulator, variable gain amplifier and necessary PLLs for frequency generation.

The previous design of the video transmitter was intended to resemble the Maxim MAX2370 evaluation board with custom tailoring to implement the reference frequency generation and filtering on-board. For the video transmitter the Q inputs were tied to mid-rail since the output from the on-screen text overlay board was single ended output only. Using the MAX412 dual op-amp package the single-ended input was converted to a differential signal for the I inputs of the transmitter. Following the design of the evaluation board the IF was chosen to be 120 MHz to utilize the tank design and simplify the video transmitter design. The reference frequency was chosen to be 19.68 MHz, close to the recommended value for the evaluation board, and supplied using the NDK NT3225SA crystal oscillator. The LO generation was chosen to be done using the MAX2609 VCO capable of supplying a frequency between 45 and 650 MHz. The transmitter uses the lower sideband of the LO mixing so using an IF of 120 MHz with a desired RF of 439.25 MHz the LO frequency would need to be 559.25 MHz.

Power Amplification and Transmittable Range:

The typical output power of the MAX2370 transmitter, when configured for maximum gain, is recorded as 10dBm or 10mW. In order to achieve the required output power of at least 1W, with intent on meeting the 5W preferred output power, the Mitsubishi RA07H4047M RF PA was to be used. From the datasheet curves the typical output power of the RF PA with a gate voltage of 3V at 440 MHz is about 8W for 20mW of input power. Given the power from the MAX2370 to be about 10mW the expected output power of the PA is 4W, which meets the required 1W minimum.

The antennas decided upon by the previous year include the M2 436-CP42 U/G Yagi antenna for the ground control and the Comet SSB-1 Whip antenna to be mounted on the platform. The choice for the Yagi antenna was due to a high gain of 16.8dB while the Whip antenna was chosen for the capability of supporting dual bands, the 440 MHz band and the 2m band used for the GPS/Telemetry transmitter. The Yagi antenna is circularly polarized while the Whip antenna has a gain of 2.15dB with linear polarization. From this and using Frii's Transmission equation shown in Equation 1 the maximum received power, given perfect line of sight, can be found as follows:

$$\lambda = \frac{c}{f} = \frac{3E8}{439.25E6} = .683m$$

$$G_T = 16.8dB = 47.86$$

$$G_R = 2.15dB = 1.64$$

$$PLF = \left|\hat{\rho}_T \cdot \hat{\rho}_R\right|^2 = \left|\left(\frac{\hat{a}_x + \hat{a}_y}{\sqrt{2}}\right) \cdot \left(\frac{\hat{a}_x + j\hat{a}_y}{\sqrt{2}}\right)\right|^2 = \frac{1}{2}$$

$$P_R = P_T G_T G_R \left(\frac{\lambda}{2\pi R}\right)^2 PLF = (4)(47.86)(1.64)\left(\frac{.683}{2\pi R}\right)^2 \left(\frac{1}{2}\right) = \frac{1.85562}{R^2} \qquad [2]$$

Work done by the previous team mentioned a required SNR of 28dB or better to yield a passable picture. The noise power here is dominated by the thermal noise of the receive antenna which is found to be kTB where k is Boltzmann's constant, T is the operating temperature, and B is the bandwidth of the antenna. Using a temperature around 75º F or 297 K and the bandwidth of the antenna being 8 MHz the thermal noise power is found to be 32.804E-15 W or -104.84dBm. For an SNR of 28dB the received signal power must be at least 28dBm higher than the noise power or -76.84dBm. This corresponds to a received power of 20.7E-12W which, using Equation 2, yields a maximum distance, R, of 299.4km. This range is not the 500km required, however given the weight and required platform lifetime, additional analysis needs to be done to determine if the transmitter is capable of outputting more power without hindering the platform. Using these numbers however, for 500km of transmittable range the transmitted power must be at least 11.16W.

Current Design:

The current design is based on the previous video transmitter design with slight alterations to schematic where necessary and the inclusion of a passive LC BPF on the IF output of the transmitter. The revisions to the previous layout aimed to minimize RF trace length and correct some power issues. The first revision of this years corrected design is still aimed at being an evaluation and test of the parts, considering the addition of on-board frequency synthesis and PA, and the layout was done in such a manner to include SMA connectors to measure the performance of the components and test points where necessary to check digital signals. The schematic is shown in Figure 2 with current layout in Figure 3.

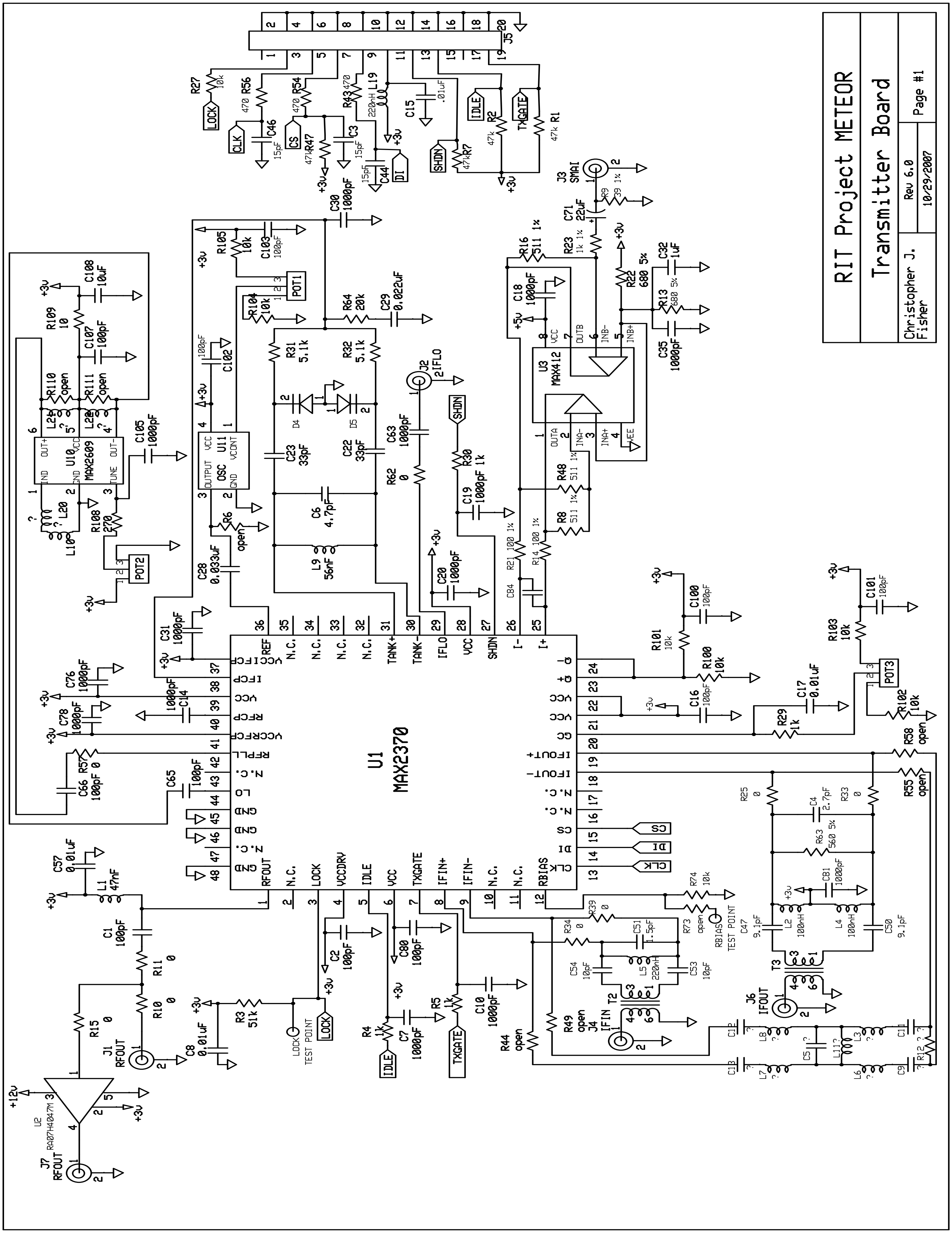

Figure 1: Current Video Transmitter schematic

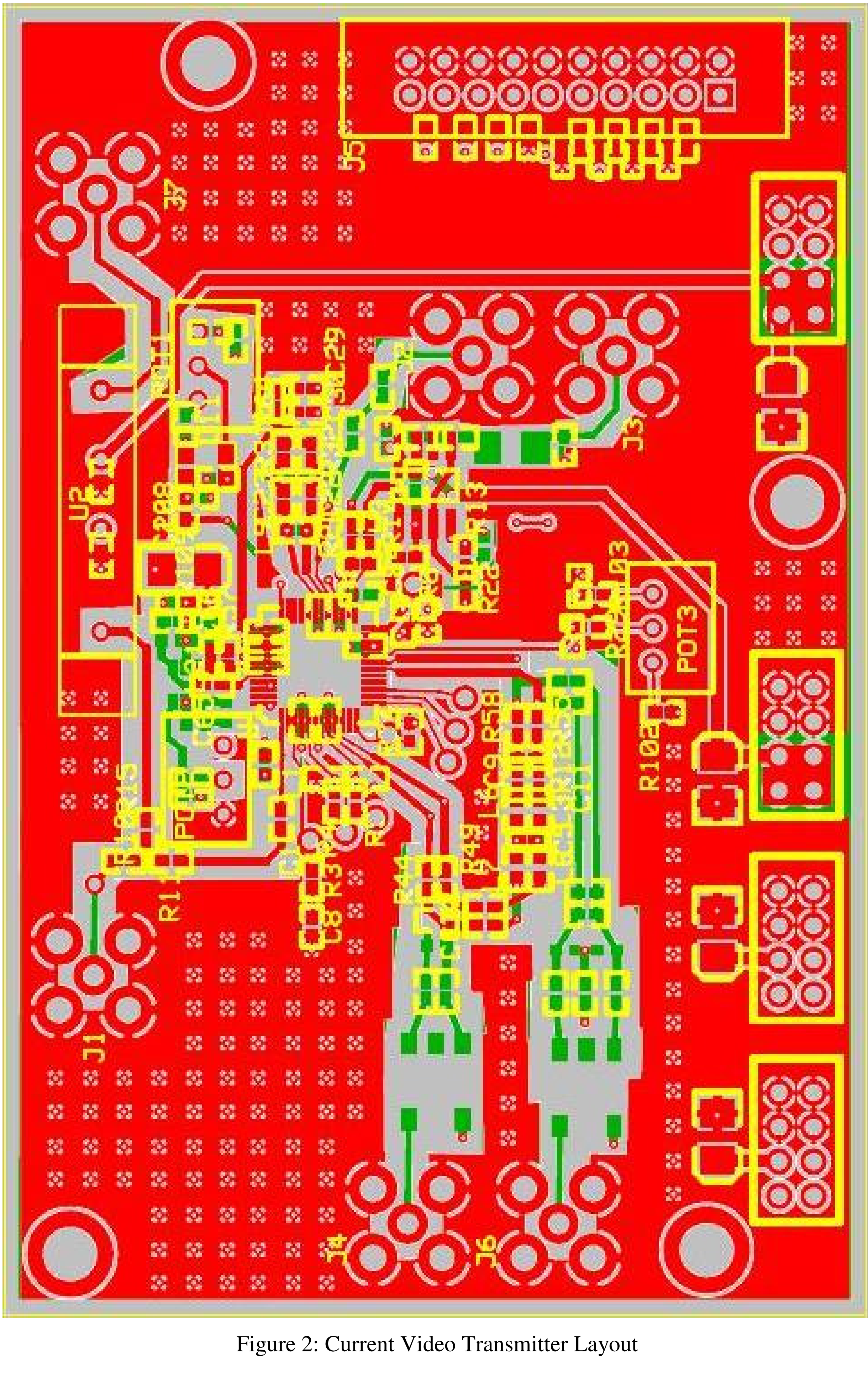

Figure 2: Current Video Transmitter Layout

Video Transmitter Test Plan:

The test plan for the Video Transmitter, shown below, is a step-by-step procedure for board population and testing. The method starts with the input of the circuit and works towards the output verifying the functionality of each block and debugging/calibrating sections as necessary.

1.) Populate power connectors and verify proper voltage levels to board components.
2.) Populate MAX412 and necessary components for single-ended to differential conversion of input signal and verify the output signal is differential without significant delay difference between the signals.
3.) Populate NDK NT3225SA and proper biasing circuitry and verify proper operation at intended frequency.
4.) Populate MAX2609 and necessary biasing circuitry and verify proper operation. May require additional tuning to achieve desired LO frequency.
5.) Populate MAX2370 and necessary circuitry for operation.
    a. Program on-board registers for proper IF and RF frequency synthesis.
    b. Set digital lines to ‘on’ states and verify proper voltage level at each input pin.
    c. Check output IFLO frequency to verify proper programming of registers.
    d. For a single-tone input signal, verify proper upconverted signal coming out of the MAX2370 on the IFOUT pins.
    e. Populate BPF components on IFOUT path and verify frequency response. Adjust values if necessary to achieve acceptable response across entire band of interest.
    f. For a single-tone input signal, verify proper signal and power level coming out of the MAX2370 on the RF pin.
6.) Populate Mitsubishi RA07H4047M and test using single-tone signal with power of 10dBm to verify expected output power.
7.) Test entire chain with varying input frequency to verify performance across band and with approximately flat response.

Future Improvements:

With the completion of test and verification of component functionality an additional filter may be necessary on the output of the PA to eliminate spurious components. Additionally, once verification is complete some of the extraneous SMA connectors may be removed to minimize parasitics and provide more space for a cleaner layout, including the removal of digital trace from under the signal traces.