Design and Development of an RF Front End Board for NIJ Public Safety Radio

S.M. Shajedul Hasan* and S.W. Ellingson

July 22, 2008

Contents

*Bradley Dept. of Electrical & Computer Engineering, 432 Durham Hall, Virginia Polytechnic Institute & State University, Blacksburg, VA 24061 USA. E-mail: hasan@vt.edu

1 Introduction

An experimental multi-band/multi-mode radio for public safety applications is being developed in Virginia Tech under a project sponsored by the U.S. Department of Justice [1]. The goal of this project is to develop and demonstrate a single radio which can operate in all the public safety frequency bands presented in [2, 3]. To provide context, Figure 1 shows a conceptual "board-level" overview of a prototype of the proposed radio, consisting of a RF front end board, RFIC transceiver board, ADC/DAC board, baseband processing board, and other control boards. The design and development of the RF front end (RFFE) board is described here.

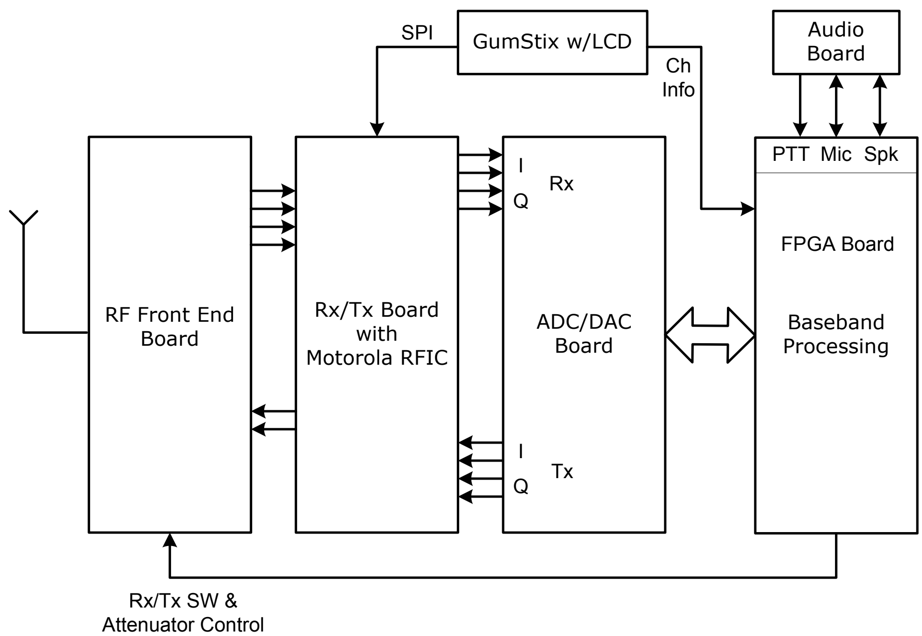


Figure 1: Conceptual board-level overview.

Figure 2 shows the image of the RF front end board.

This report is organized as follows. Section 2 presents the summary of the input/output ports of RFFE board. Section 3 describes the signal path planning and Section 4 presents multiplexer design methodology. Section 5 and 6 presents the circuit description of the amplifier and attenuator respectively. Section 6 describes the various jumper and switch settings. Section 7 concludes the report presenting the total cost. Finally, three appendices present the bill of materials, complete schematic and layout images.

2 RFFE Board Overview

Figure 3 and Table 1 present all the input/output ports of the RFFE board.

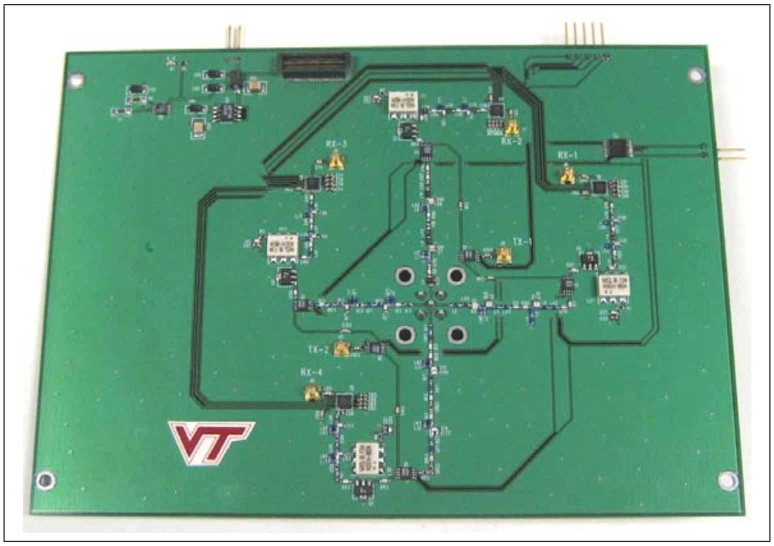


Figure 2: Image of RF Front End board.

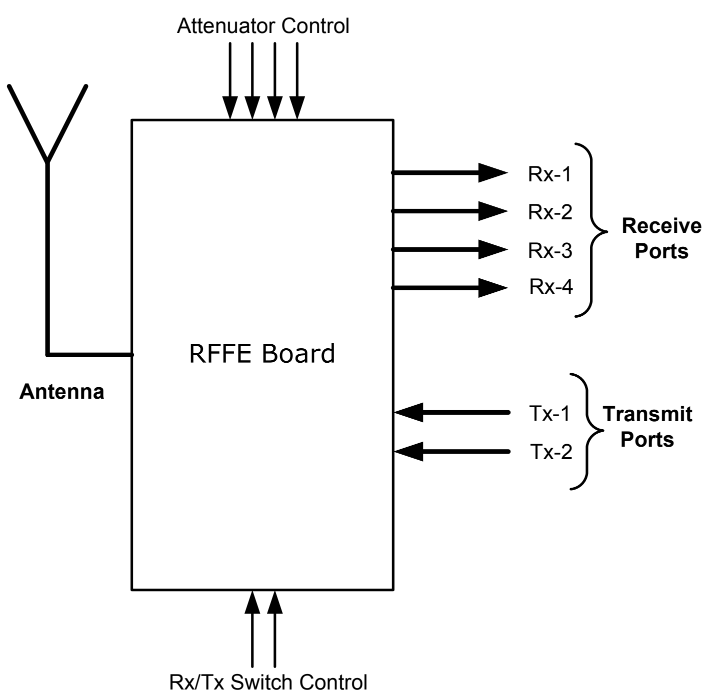


Figure 3: Summary of RFFE board.

Function	Port Name	Conn. Name	Characteristics
Receive Ports	RX-1	J6	RF Mux Ch-1 receive port
	RX-2	J7	RF Mux Ch-2 receive port
	RX-3	J8	RF Mux Ch-3 receive port
	RX-4	J9	RF Mux Ch-4 receive port
Transmit Ports	TX-1	J2	RF Mux Ch-1 or Ch-2 transmit port
	TX-2	J3	RF Mux Ch-3 or Ch-4 transmit port
Attenuator Control	ATT_CTL	J5	Attenuator control signals
Rx/Tx switch	SW_CTL	J4	Rx/Tx switch control signals

Table 1: Input/Output ports of the RFFE board.

3 Analog Signal Path Planning

This section describes some considerations in planning of the RFFE analog signal path. "Analog signal path" is defined here as the section beginning at the antenna terminals and ending at the input to the analog-to-digital converter (ADC). The analog signal path under consideration contains all the circuitry in the RFFE board, which includes multiplexer, amplifier, additional filtering and attenuators, and the RFIC transceiver board described in [4].

This signal path requirements are developed following the general strategy described in [5]. In order to receive the signal and digitize it appropriately the level of incoming signal should meet the specification of ADC. In this document we use the specifications of Analog Devices AD9248 ADC described in [6]. The relevant parameters and design constraints are shown in Table 2. Given this information, we can compute the required number of bits:

$$N_b \geq 1.67 \log_{10} \frac{P_t \gamma_r}{P_{ext} \delta_r} \tag{1}$$

where P_t is the sum of the total receive signal power plus P_{ext}, which is approximately equal to the total external noise power calculated using the table from [7]. Also, the minimum required gain in the analog signal path G_{min}, and the maximum allowed gain G_r can be found using the following equations:

$$G_{\min} = \frac{P_Q \gamma_q}{P_{ext}} \tag{2}$$

$$G_r = \frac{P_{clip} \delta_r}{P_t} \tag{3}$$

A summary of the analysis is provided in Table 3, which shows the values of various design parameters (N_b,G_{min},G_r) corresponding to our frequency bands. Table 4, 5, 6, and 7 present the GNI analysis of the analog section for various channels using nominal gain.

Parameter	**Value**	**Definition**
P_{clip}	+4 dBm	ADC full scale
P_Q	-62 dBm	ADC quantization noise power, referenced to ADC input
γ_q	+10 dB	Desired ratio of P_{ext} to P_Q
δ_r	-10 dB	Maximum acceptable input power relative to P_{clip}

Table 2: Assumed analog-to-digital converter (ADC) specifications and associated design constraints.

Frequency	P_t	P_{ext}	N_b	G_{min}	G_r
138-174 MHz	-90.0 dBm	-122.5 dBm	8.8	70.5 dB	84.0 dB
220-222 MHz	-90.0 dBm	-128.1 dBm	9.7	76.1 dB	84.0 dB
406-512 MHz	-90.0 dBm	-135.3 dBm	10.9	83.3 dB	84.0 dB
764-862 MHz	-90.0 dBm	-142.9 dBm	12.2	90.9 dB	84.0 dB

Table 3: Design implications (N_b,G_{min},G_r) corresponding to various choices of frequency range and response. Gain here defined is defined from antenna terminals to ADC input.

Section	**Gain (dB)**	**IP3 (dBm)**	**Noise Figure (dB)**
Muiltiplexer	-8	200	8
Preamp	25	12.9	2.7
Filter	-1	200	1
Attenuator	-1	30	1
RFIC	69	-6	7
GNI Analysis	84	-21.0	10.75
Sensitivity	-117.8 dBm		

Table 4: GNI analysis of Channel-1 for nominal gain.

Section	**Gain (dB)**	**IP3 (dBm)**	**Noise Figure (dB)**
Muiltiplexer	-4	200	4
Preamp	25	12.9	2.7
Filter	-1	200	1
Attenuator	-5	30	5
RFIC	69	-6	7
GNI Analysis	84	-21.0	6.84
Sensitivity	-120.8 dBm		

Table 5: GNI analysis of Channel-2 for nominal gain.

Section	Gain (dB)	IP3 (dBm)	Noise Figure (dB)
Muiltiplexer	-1	200	1
Preamp	25	12.9	2.7
Filter	-1	200	1
Attenuator	-8	30	8
RFIC	69	-6	7
GNI Analysis	84	-21.0	3.98
Sensitivity	-127.8 dBm		

Table 6: GNI analysis of Channel-3 for nominal gain.

Section	Gain (dB)	IP3 (dBm)	Noise Figure (dB)
Muiltiplexer	-5.0	200	5.0
Preamp	25	12.9	2.7
Filter	-1	200	1
Attenuator	-1.0	30	1.0
RFIC	66	-6	7
GNI Analysis	84	-24.0	7.75
Sensitivity	-125.5 dBm		

Table 7: GNI analysis of Channel-4 for nominal gain.

4 Description of Multiplexer Section

A four channel multiplexer has been designed using the methodology described in [8]. As we know sensitivity depends on signal to noise ratio and external noise can be very strong in practical scenarios, especially at low frequencies (below ~400 MHz). So, when the ratio of external noise to internal noise is large, additional effort to minimize reflection co-efficient or internal noise will have little effect on sensitivity. Therefore, our main idea is to design a multiplexer, which may be poorly matched with the antenna impedance, in such a way that the front end is dominated by the external noise and provide acceptable sensitivity.

In our design we use a simple monopole antenna ANT-433-CW from Antenna Factor. The length of this antenna is 17.3 cm long and diameter is 6 mm. The measured impedance of this antenna is shown in Figure 4.

Figure 5 shows the response of the designed multiplexer optimized to match with the antenna impedance to provide acceptable sensitivity. These results are expressed in terms of transducer power gain (TPG), defined as the ratio of power delivered by a matching network to a load, to the power delivered to a perfectly matched load directly from the antenna. Note that the performance is unacceptable, especially in the 138-174 MHz band. However, this poor matching gives us the sensitivity of -117.8 dBm, which is acceptable for our receiver.

Each of the channel of our designed multiplexer uses fifth order chebyshev topology, which is shown in Figure 6. Table 8 shows the component values of multiplexer before and

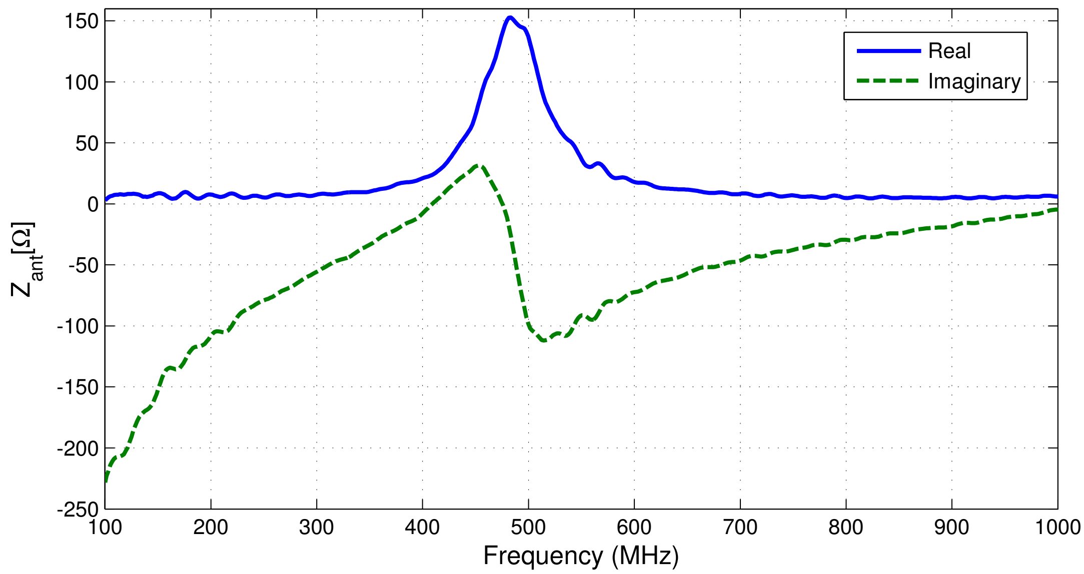


Figure 4: Antenna impedance.

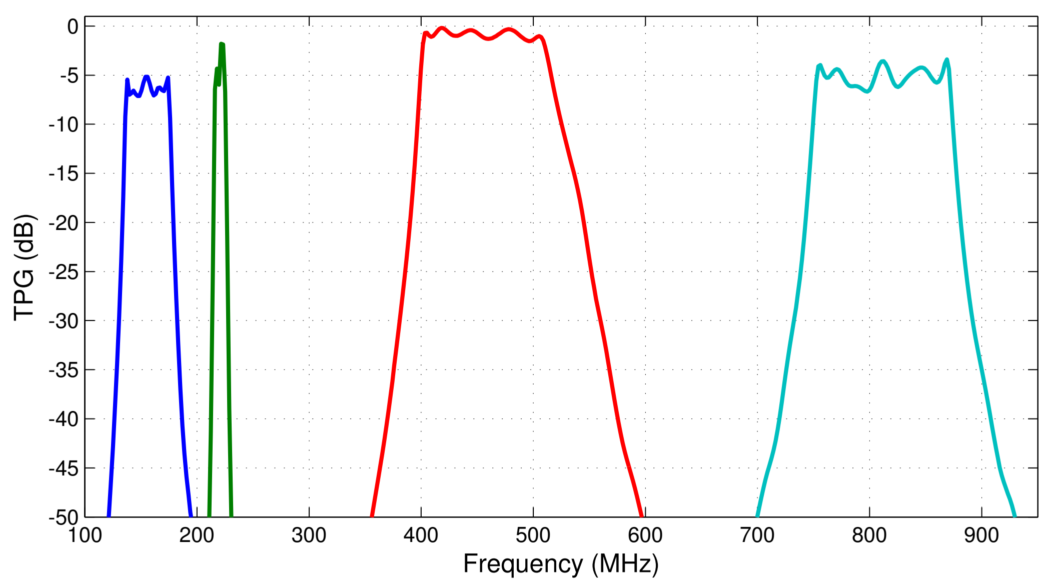


Figure 5: Multiplexer response.

after the optimization.

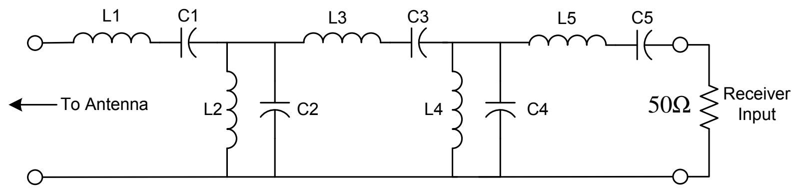


Figure 6: Multiplexer topology of each channel.

Component	**Channel–1**		**Channel–2**		**Channel–3**		**Channel–4**	
	Before	After	Before	After	Before	After	Before	After
L1 (nH)	377.1	306.0	1357.4	1350	111.2	120	114.9	130
C1 (pF)	2.8	5.4	0.4	0.41	1.1	1.1	0.3	0.308
L2 (nH)	9.7	7.8	1.3	1.32	3.1	3.1	0.9	1.15
C2 (pF)	108.7	139.0	391.4	399	39.0	39.0	42.8	33.8
L3 (nH)	561.6	426.0	2021.9	2027	173.4	175	182.0	178
C3 (pF)	1.9	2.45	0.3	0.255	0.7	0.7	0.2	0.216
L4 (nH)	9.7	9.0	1.3	1.32	3.1	3.1	0.9	1.15
C4 (pF)	108.7	118.0	391.4	393.0	39.0	39.0	42.8	33.7
L5 (nH)	377.1	246.0	1357.4	1380	112.2	110	114.9	105.6
C5 (pF)	2.8	4.33	0.4	0.375	1.1	1.1	0.3	0.368

Table 8: Component values of the multiplexer before and after the optimization.

5 Description of Amplifier Section

In our design we use GALI-74 amplifier from Minicircuits. This amplifier is chosen mainly for its low cost and low noise characteristics. ADCH-80A, a wideband choke from Minicircuits, is also used to minimize the RF loss caused by the DC biasing resistor. The circuit of this amplifier is designed for 9V DC bias. Fig. 7 shows the circuit diagram example for the amplifier. Detailed circuit diagrams can be found in "Amplifier" sheet in Appendix B. This sheet also contains four fifth order chebyshev bandpass filters after each of the amplifiers to perform additional filtering.

6 Description of Attenuator Section

To control the attenuation of the received signal we use a 5-bit digitally controlled attenuator HMC470LP3 from Hittite Microwave Inc. Fig. 8 shows the circuit diagram of the attenuator. Detailed circuit diagrams can be found in "Attenuator" sheet in Appendix B.

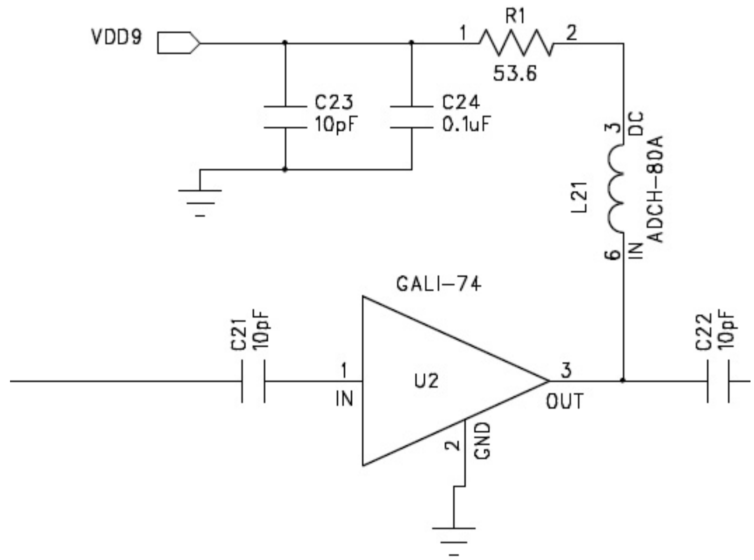


Figure 7: Amplifier section (the unconnected line on the left side connects the input port of the amplifier with the RX switches and right side goes to input of the bandpass filter).

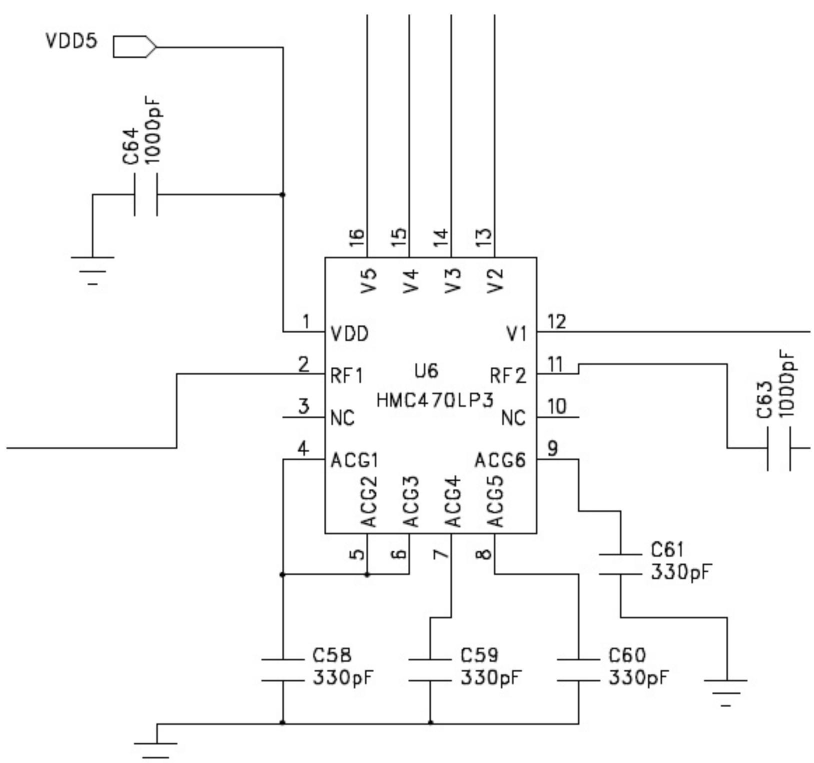


Figure 8: Attenuator section (RF1 and RF2 are the input and output port of the attenuator. Other unconnected lines in the figure are the control signal to vary the attenuation).

7 Description of Power Supply Section

One 9V supply voltage for amplifiers and one 5V supply voltage for RF switches and attenuators, have been created from a single 16V power source. This 16V input voltage is fed into a 1.1A low dropout regulator IC LT1965 to create a 9V positive voltage. 5V regulated voltage is supplied by the 500 mA low dropout regulator ICs LT763. Both of these regulator ICs are manufactured by Linear Technology Inc. Detailed circuit diagrams can be found in "Power Supply" sheet in Appendix B.

8 Description of the Settings

Table 9 shows the specification of attenuator control signals to get various attenuation.

V1 16dB	**V2** 8dB	**v3** 4dB	**V4** 2dB	**V5** 1dB	**ATT State**
High	High	High	High	High	Insertion Loss
High	High	High	High	Low	1dB
High	High	High	Low	High	2dB
High	High	Low	High	High	4dB
High	Low	High	High	High	8dB
Low	High	High	High	High	16dB
Low	Low	Low	Low	Low	31dB

Table 9: Attenuator control signals.

Table 10 shows the Rx/Tx swtich control signals.

S0	**S1**	**Rx/Tx Mode**
High	X	RX Mode
Low	Low	TX Mode (Ch.1 or Ch.3)
Low	High	TX Mode (Ch.2 or Ch.4)

Table 10: Rx/Tx Switch Control Signals.

9 Summary

A summary of the cost for one RFFE board is given in Table 11. Since we prepared just two boards for the present study using the quickest manufacturing time, the PCB fabrication and assembly cost is not representative of the cost to build the same device in large quantities.

Component	**Quantity**	**Price(US $)**
Regulator ICs	2	8.58
Amplifier	4	18.80
RF Choke	4	59.0
Attenuator	4	15.32
RF Switch	6	7.08
Capacitor	109	16.35
Inductor	61	45.75
Resistor	7	1.00
MMCX Connector	6	60.30
Other Connectors	5	10.0
Other Components	3	3.50
	Subtotal	**245.68**
PC Board	1	450.00
PC Board Assembly	1	925.00
	Total	**1620.68**

Table 11: Summary of the cost for one RFFE board.

References

[1] NIJ project web site, http://www.ece.vt.edu/swe/chamrad/.

[2] S. W. Ellingson, “Phase I Technical Report,” Virginia Tech, VA, Tech. Rep. 15, Oct. 2006. [Online]. Available: http://www.ece.vt.edu/swe/chamrad/.

[3] S. W. Ellingson, S.M. Hasan, M. Harun, and C.R. Anderson, “Phase II Technical Report,” Virginia Tech, VA, Tech. Rep. 23, Oct. 2007. [Online]. Available: http://www.ece.vt.edu/swe/chamrad/.

[4] S.M. Hasan and S.W. Ellingson, “Design and Development of an Evaluation Board with RFIC Ver. 4,” Virginia Tech, VA, Tech. Rep. 22, Sep. 2007. [Online]. Available: http://www.ece.vt.edu/swe/chamrad/.

[5] D.W.A. Taylor III, *Design of Ultrawideband Digitizing Receivers for the VHF Low Band*, M.S. Thesis, Virginia Polytechnic Institute & State University, 2006. [Online]. Available: http://scholar.lib.vt.edu/theses/available/etd-05162006-161217/.

[6] S.M. Hasan and S.W. Ellingson, “ Design and Development of an ADC/DAC Evaluation Board for NIJ Public Safety Radio,” Virginia Tech, VA, Tech. Rep. 24, Nov. 2007. [Online]. Available: http://www.ece.vt.edu/swe/chamrad/.

[7] S.M. Hasan and S.W. Ellingson, “ Optimum Noise Figure Specification,” Virginia Tech, VA, Tech. Rep. 20, Apr. 2007. [Online]. Available: http://www.ece.vt.edu/swe/chamrad/.

[8] S.M. Hasan and S.W. Ellingson, “Multiband Antenna-Receiver Integration using an RF Multiplexer with Sensitivity-Constrained Design”, IEEE 2008 International Symposium on Antenna and Propagation, San Diego, July, 2008.

Appendices

A Bill of Materials

This section presents the bill of materials.

Bill of Materials
RFFE Board, Ver.2.0
MPRG/Virginia Tech
Prepared By: S.M. Hasan, Date: MAR 11, 2008

Item	Qty	Reference	Part Name	Package	Manufacturer	Manufacturer Part#	Distributor	Distributor Part#	Description
1	1	U1	74VHCT04AMTC	14-TSSOP	FAIRCHILD	74VHCT04AMTC	Mouser	512-74VHCT04AMTC	HEX INVERTER
2	4	L21 L27 L33 L39	ADCH-80A	CD542	Minicircuits	ADCH-80A+	Minicircuits	ADCH-80A+	RF Choke
3	1	C93	0.01uF 100V	CAP_1210	AVX Corporation	12101C103KAT2A	Digikey	478-1608-1-ND	SURFACE MOUNT CAPACITOR 0.098 X 0.126 INCHES
4	1	C92	1uF 100V	CAP_1210	AVX Corporation	12101C105KAT2A	Digikey	478-2570-1-ND	SURFACE MOUNT CAPACITOR 0.098 X 0.126 INCHES
5	4	C24 C33 C42 C51	0.1uF 50V	CAP_0603	Murata Electronics	GRM188R71H104KA93D	Digikey	490-1519-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
6	3	C52 C54 C56	0.3pF 50V	CAP_0603	AVX Corporation	06035J0R3PBTTR	Digikey	478-2801-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
7	1	C86	0.4pF 250V	CAP_0603	AVX Corporation	SQCSVA0R4BAT1A	Digikey	478-3483-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
8	3	C10 C36 C99	0.5pF 100V	CAP_0603	Murata Electronics	GQM1885C2AR50CB01D	Digikey	490-3551-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
9	1	C106	0.6pF 250V	CAP_0603	AVX Corporation	SQCSVA0R6BAT1A	Digikey	478-3484-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
10	4	C8 C13 C78 C107	0.7pF 50V	CAP_0603	AVX Corporation	06035J0R7PBSTR	Digikey	478-4445-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
11	4	C16 C34 C38 C101	0.8pF 250V	CAP_0603	AVX Corporation	SQCSVA0R8BAT1A	Digikey	478-3485-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
12	3	C20 C105 C109	0.9pF 50V	CAP_0603	AVX Corporation	06035J0R9PBTTR	Digikey	478-2807-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
13	2	C11 C15	1.1pF 250V	CAP_0603	AVX Corporation	SQCSVA1R1BAT1A	Digikey	478-3487-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
14	4	C43 C47 C97 C108	1.5pF 250V	CAP_0603	AVX Corporation	SQCSVA1R5BAT1A	Digikey	478-3489-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
15	1	C27	1.8pF 250V	CAP_0603	AVX Corporation	SQCSVA1R8BAT1A	Digikey	478-3490-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
16	14	C63-64 C71-72 C79-80 C87-88 C96 C98 C100 C102-104	1000pF 50V	CAP_0603	AVX Corporation	06035C102KAT2A	Digikey	478-1215-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
17	2	C2 C4	100pF 50V	CAP_0603	AVX Corporation	06035A101KAT2A	Digikey	478-3717-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
18	12	C21-23 C30-32 C39-41 C48-50	10pF 250V	CAP_0603	AVX Corporation	SQCSVA100JAT1A	Digikey	478-3502-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
19	2	C26 C28	110pF 100V	CAP_0603	Murata Electronics	GRM1885C2A111JA01D	Digikey	490-1352-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
20	1	C70	18pF 250V	CAP_0603	AVX Corporation	SQCSVA180JAT1A	Digikey	478-3505-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
21	3	C6 C18 C45	1pF 250V	CAP_0603	AVX Corporation	SQCSVA1R0BAT1A	Digikey	478-3486-1-ND	SURFACE MOUNT CAPACITOR 0603 Size

Item	Qty	Reference	Part Name	Package	Manufacturer	Manufacturer Part#	Distributor	Distributor Part#	Description
22	1	C57	2.4pF 250V	CAP_0603	AVX Corporation	SQCSVA2R4BAT1A	Digikey	478-3493-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
23	2	C25 C29	2.7pF 250V	CAP_0603	AVX Corporation	SQCSVA2R7BAT1A	Digikey	478-3494-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
24	2	C35 C37	200pF 100V	CAP_0603	Murata Electronics	GRM1885C2A201JA01D	Digikey	490-1358-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
25	16	C58-61 C66-69 C74-77 C82-85	330pF 50V	CAP_0603	Panasonic	ECJ-1VC1H331J	Digikey	PCC331ACVCT-ND	SURFACE MOUNT CAPACITOR 0603 Size
26	5	C17 C19 C53 C55 C95	33pF 250V	CAP_0603	AVX Corporation	SQCSVA330JAT1A	Digikey	478-3511-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
27	2	C7 C9	360pF 100V	CAP_0603	Murata Electronics	GRM1885C2A361JA01D	Digikey	490-1364-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
28	6	C12 C14 C44 C46 C62 C81	39pF 250V	CAP_0603	AVX Corporation	SQCSVA390JAT1A	Digikey	478-3512-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
29	1	C1	3pF 250V	CAP_0603	AVX Corporation	SQCSVA3R0BAT1A	Digikey	478-3495-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
30	1	C65	4.7pF 250V	CAP_0603	AVX Corporation	SQCSVA4R7CAT1A	Digikey	478-3498-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
31	1	C3	5.1pF 100V	CAP_0603	Murata Electronics	GQM1885C2A5R1CB01D	Digikey	490-3559-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
32	1	C5	8.2pF 250V	CAP_0603	AVX Corporation	SQCSVA8R2CAT1A	Digikey	478-3501-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
33	1	C73	9.1pF 50V	CAP_0603	Murata Electronics	GQM1885C1H9R1CB01D	Digikey	490-3569-1-ND	SURFACE MOUNT CAPACITOR 0603 Size
34	4	C89-91 C94	10uF 16V	CAP_3216	Rohm	TCA1C106M8R	Digikey	511-1473-1-ND	CAP TANTALUM
35	1	J11	CONN_SAM8128_HEADER	Plug	Samtec Inc	QTE-020-01-X-D-A	Digikey	SAM8128-ND	HIGH SPEED HEADER 40 PINS
36	1	J1	CONN_RPSMA-THROUGH	SMA	Linx Technologies	CONREVSMA001	Digikey	CONREVSMA001-ND	SMA Through Hole Connector
37	4	U2-5	GALI-74	DF782	Mincircuits	GALI-74+	Minicircuits	GALI-74+	Monolithic Amplifier
38	6	S1-6	HMC284MS8G	MS8G	HITTITE	HMC284MS8G	HITTITE	HMC284MS8G	RF SWITHC
39	4	U6-9	HMC470LP3	LP3	HITTITE	HMC470LP3	HITTITE	HMC470LP3	5 BIT DIGITAL ATTENUATOR
40	1	D1	LED_SMT	SMT	LITE-ON	LTST-C190GKT	Digikey	160-1183-1-ND	LIGHT EMITTING DIODE
41	1	E2	LT1965	MSOP8G	LINEAR TECHNOLOGY	LT1965	Digikey	LT1965IMS8E#PBF-ND	LINEAR LDO REGULATOR
42	4	L17 L19 L41 L43	1.6nH	L_0603	Coilcraft	0603CS-1N6X_LU	Coilcraft	0603CS-1N6X_LU	Surface Mount Inductor 0603 Size
43	1	L30	1000nH	L_0603	Coilcraft	0603LS-102X_LB	Coilcraft	0603LS-102X_LB	Surface Mount Inductor 0603 Size
44	4	L15-16 L20 L56	100nH	L_0603	Coilcraft	0603CS-R10X_LU	Coilcraft	0603CS-R10X_LU	Surface Mount Inductor 0603 Size
45	1	L58	10nH	L_0603	Coilcraft	0603CS-10NX_LU	Coilcraft	0603CS-10NX_LU	Surface Mount Inductor 0603 Size
46	1	L18	110nH	L_0603	Coilcraft	0603CS-R11X_LU	Coilcraft	0603CS-R11X_LU	Surface Mount Inductor 0603 Size
47	2	L8 L10	1200nH	L_0603	Coilcraft	0603LS-122X_LB	Coilcraft	0603LS-122X_LB	Surface Mount Inductor 0603 Size
48	5	L11 L36 L40 L42 L44	120nH	L_0603	Coilcraft	0603CS-R12X_LU	Coilcraft	0603CS-R12X_LU	Surface Mount Inductor 0603 Size

Item	Qty	Reference	Part Name	Package	Manufacturer	Manufacturer Part#	Distributor	Distributor Part#	Description
49	1	L2	12nH	L_0603	Coilcraft	0603CS-12NX_LU	Coilcraft	0603CS-12NX_LU	Surface Mount Inductor 0603 Size
50	1	L54	180nH	L_0603	Coilcraft	0603CS-R18X_LU	Coilcraft	0603CS-R18X_LU	Surface Mount Inductor 0603 Size
51	2	L7 L53	2.2nH	L_0603	Coilcraft	0603CS-2N2X_LU	Coilcraft	0603CS-2N2X_LU	Surface Mount Inductor 0603 Size
52	6	L29 L31 L62-65	2.6nH	L_0603	Coilcraft	0604HQ-2N6XJLB	Coilcraft	0604HQ-2N6XJLB	Surface Mount Inductor 0603 Size
53	1	L5	210nH	L_0603	Coilcraft	0603HP-R21X_LU	Coilcraft	0603HP-R21X_LU	Surface Mount Inductor 0603 Size
54	1	L46	22nH	L_0603	Coilcraft	0603CS-22NX_LU	Coilcraft	0603CS-22NX_LU	Surface Mount Inductor 0603 Size
55	2	L6 L50	2700nH	L_0603	Coilcraft	0603LS-272X_LB	Coilcraft	0603LS-272X_LB	Surface Mount Inductor 0603 Size
56	1	L1	270nH	L_0603	Coilcraft	0603HP-R27X_LU	Coilcraft	0603HP-R27X_LU	Surface Mount Inductor 0603 Size
57	4	L9 L35 L37 L51	3.3nH	L_0603	Coilcraft	0603HP-3N3X_LU	Coilcraft	0603HP-3N3X_LU	Surface Mount Inductor 0603 Size
58	1	L59	30nH	L_0603	Coilcraft	0603HP-30NX_LU	Coilcraft	0603HP-30NX_LU	Surface Mount Inductor 0603 Size
59	3	L45 L47 L49	36nH	L_0603	Coilcraft	0603HP-36NX_LU	Coilcraft	0603HP-36NX_LU	Surface Mount Inductor 0603 Size
60	3	L3 L22 L26	390nH	L_0603	Coilcraft	0603CS-R39X_LU	Coilcraft	0603CS-R39X_LU	Surface Mount Inductor 0603 Size
61	1	L48	4.3nH	L_0603	Coilcraft	0603HP-4N3X_LU	Coilcraft	0603HP-4N3X_LU	Surface Mount Inductor 0603 Size
62	1	L4	4.7nH	L_0603	Coilcraft	0603HP-4N7X_LU	Coilcraft	0603HP-4N7X_LU	Surface Mount Inductor 0603 Size
63	3	L12 L14 L61	5.6nH	L_0603	Coilcraft	0603HP-5N6X_LU	Coilcraft	0603HP-5N6X_LU	Surface Mount Inductor 0603 Size
64	1	L24	560nH	L_0603	Coilcraft	0603LS-561X_LB	Coilcraft	0603LS-561X_LB	Surface Mount Inductor 0603 Size
65	2	L55 L57	6.8nH	L_0603	Coilcraft	0603HP-6N8X_LU	Coilcraft	0603HP-6N8X_LU	Surface Mount Inductor 0603 Size
66	2	L28 L32	680nH	L_0603	Coilcraft	0603LS-681X_LB	Coilcraft	0603LS-681X_LB	Surface Mount Inductor 0603 Size
67	1	L60	68nH	L_0603	Coilcraft	0603HP-68NX_LU	Coilcraft	0603HP-68NX_LU	Surface Mount Inductor 0603 Size
68	1	L13	75nH	L_0603	Coilcraft	0603HP-75NX_LU	Coilcraft	0603HP-75NX_LU	Surface Mount Inductor 0603 Size
69	1	L52	827nH	L_0603	Coilcraft	0603LS-821X_LB	Coilcraft	0603LS-821X_LB	Surface Mount Inductor 0603 Size
70	2	L34 L38	82nH	L_0603	Coilcraft	0603HP-82NX_LU	Coilcraft	0603HP-82NX_LU	Surface Mount Inductor 0603 Size
71	2	L23 L25	9.5nH	L_0603	Coilcraft	0603HP-9N5X_LU	Coilcraft	0603HP-9N5X_LU	Surface Mount Inductor 0603 Size
72	6	J2-3 J6-9	MMCX_PLUG	MMCX	Emerson	135-3801-201	Digikey	J601-ND	MMCX CONNECTOR
73	2	J4 J10	RA_SINGLEHEADER_2PIN	Male Header	TYCO	87232-2	Digikey	A28764-ND	2-Pin R/A Single Row Header

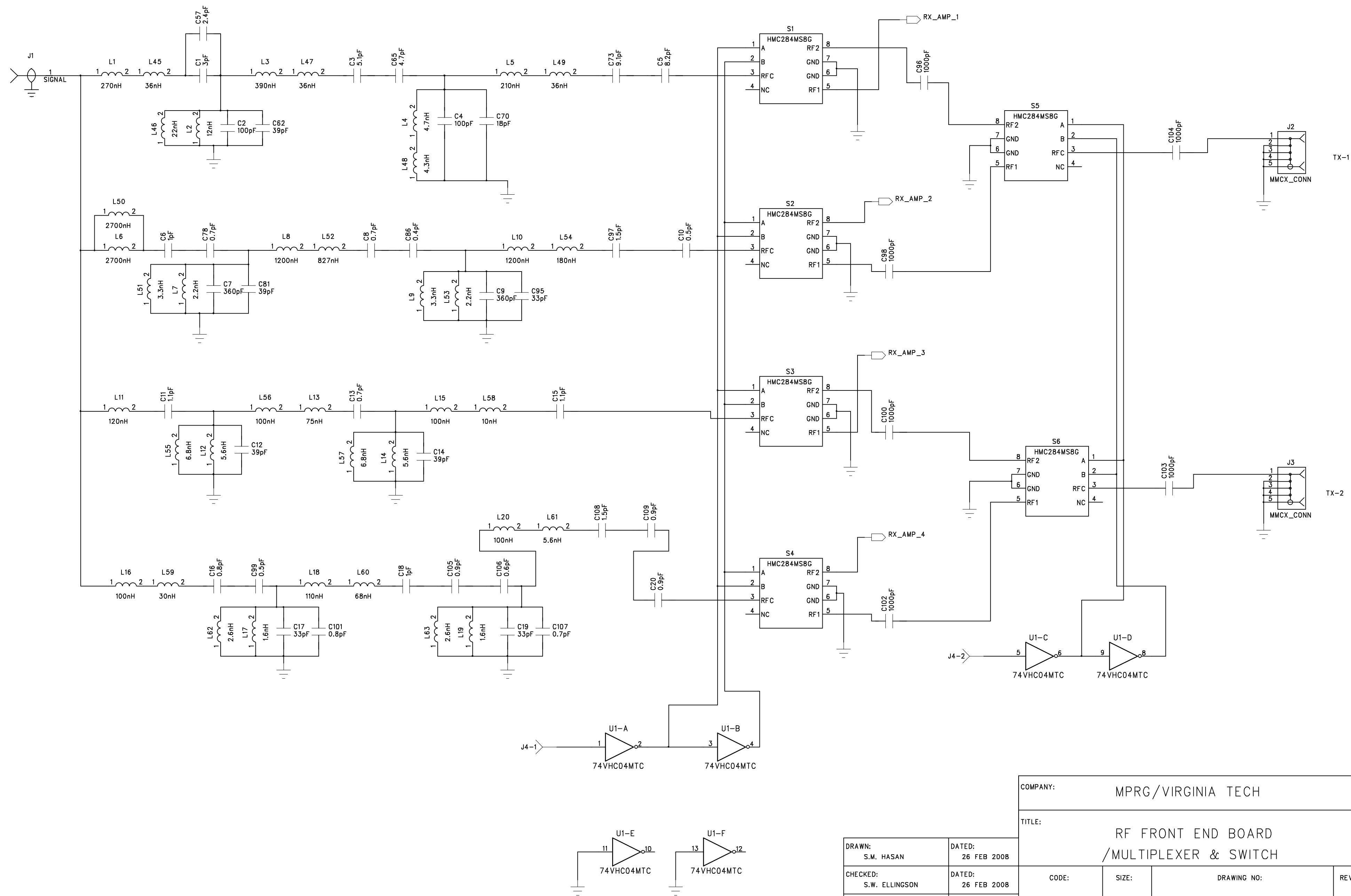
Item	Qty	Reference	Part Name	Package	Manufacturer	Manufacturer Part#	Distributor	Distributor Part#	Description
74	1	J5	RA_SINGLEHEADER_5PIN	Male Header	TYCO	87232-5	Digikey	A28770-ND	5-Pin R/A Single Row Header
75	4	R1-4	53.6 1/10W	RES_0603	Panasonic	ERJ-3EKF53R6V	Digikey	P53.6HCT-ND	SURFACE MOUNT RESISTOR 0603 Size
76	1	R5	698 1/10W	RES_0603	Rohm	MCR03EZPFX6980	Digikey	RHM698HCT-ND	SURFACE MOUNT RESISTOR 0603 Size
77	1	R6	26.1K 1/4W	RES_1206	Rohm	MCR18EZHF2612	Digikey	RHM26.1KFCT-ND	SURFACE MOUNT RESISTOR 1206 Size
78	1	R7	4.02K 1/14W	RES_1206	Rohm	MCR18EZHF4021	Digikey	RHM4.02KFCT-ND	SURFACE MOUNT RESISTOR 1206 Size
79	1	E1	SM_BEADS_DIFF	SMT	FAIR-RITE PRODUCTS CORP	2743019447	Mouser	623-2743019447LF	SM BEADS DIFFERENTIAL
80	1	U10	REGULATOR	SO-8	Linear Technology	LT1763CS8-5	Digikey	LT1763CS8-5-ND	Linear Regulator

B Schematic

This section presents the schematic of the RFFE board. This schematic contains the following four pages-

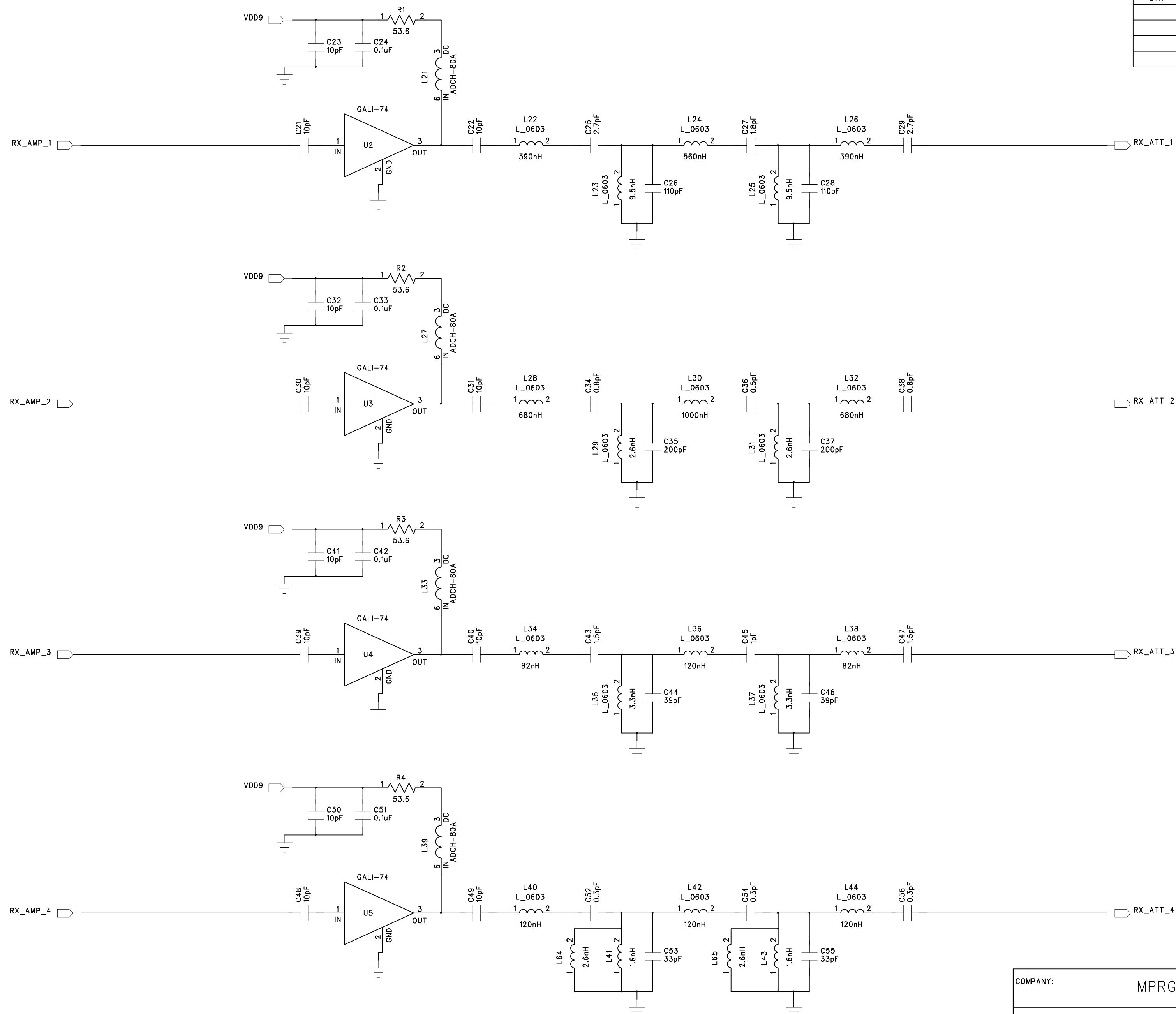
- Multiplexer and Switch Circuits
- Amplifier Circuits
- Attenuator Circuits
- Power Supply Circuits

REVISION RECORD			
LTR	ECO NO:	APPROVED:	DATE:



DRAWN: S.M. HASAN	DATED: 26 FEB 2008	COMPANY: MPRG/VIRGINIA TECH				
CHECKED: S.W. ELLINGSON	DATED: 26 FEB 2008	TITLE: RF FRONT END BOARD /MULTIPLEXER & SWITCH				
QUALITY CONTROL:	DATED:	CODE:	SIZE: C	DRAWING NO:		REV: 2.0
RELEASED:	DATED:	SCALE:			SHEET: 1 OF 4	

REVISION RECORD			
LTR	ECO NO:	APPROVED:	DATE:

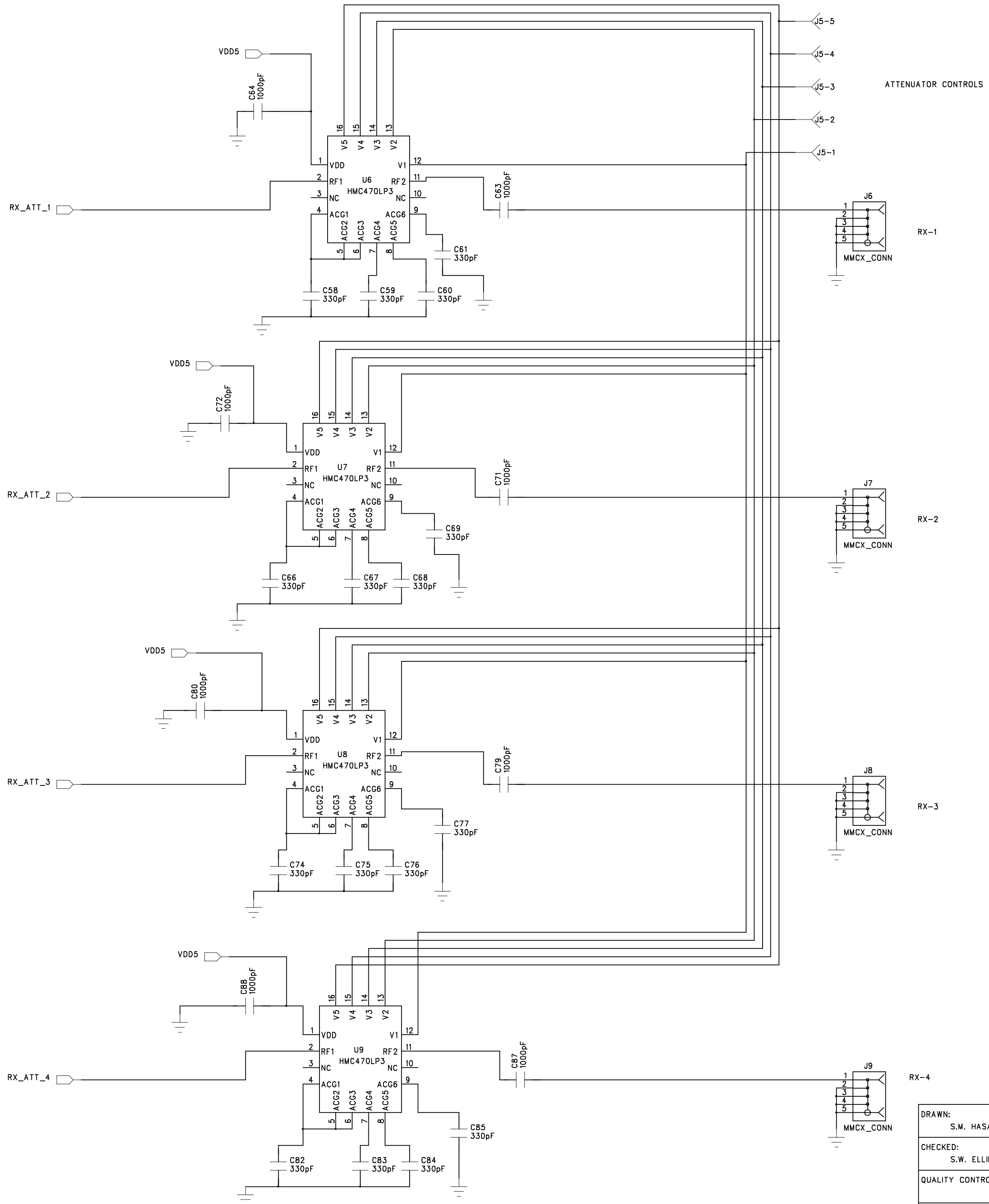


COMPANY:	MPRG/VIRGINIA TECH
TITLE:	RF FRONT END BOARD /AMPLIFIER

DRAWN: S.M. HASAN	DATED: 26 FEB 2008
CHECKED: S.W. ELLINGSON	DATED: 26 FEB 2008
QUALITY CONTROL:	DATED:
RELEASED:	DATED:

CODE:	SIZE:	DRAWING NO:	REV:
			2.0

SCALE: SHEET: 2 OF 4



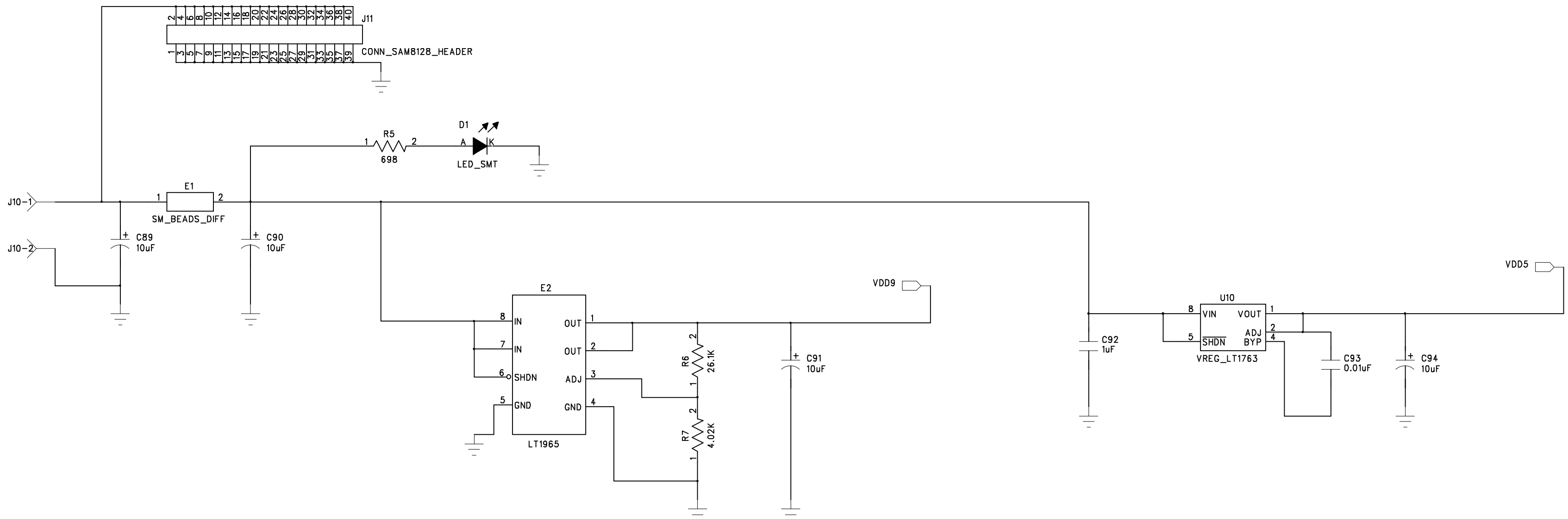
REVISION RECORD			
LTR	ECO NO:	APPROVED:	DATE:

COMPANY:	MPRG/VIRGINIA TECH
TITLE:	RF FRONT END BOARD /ATTENUATOR

DRAWN: S.M. HASAN	DATED: 26 FEB 2008
CHECKED: S.W. ELLINGSON	DATED: 26 FEB 2008
QUALITY CONTROL:	DATED:
RELEASED:	DATED:

CODE:	SIZE:	DRAWING NO:	REV: 2.0
SCALE:		SHEET: 3 OF 4	

REVISION RECORD			
LTR	ECO NO:	APPROVED:	DATE:



DRAWN: S.M. HASAN	DATED: 26 FEB 2008
CHECKED: S.W. ELLINGSON	DATED: 26 FEB 2008
QUALITY CONTROL:	DATED:
RELEASED:	DATED:

COMPANY: MPRG/VIRGINIA TECH

TITLE: RF FRONT END BOARD /POWER SUPPLY

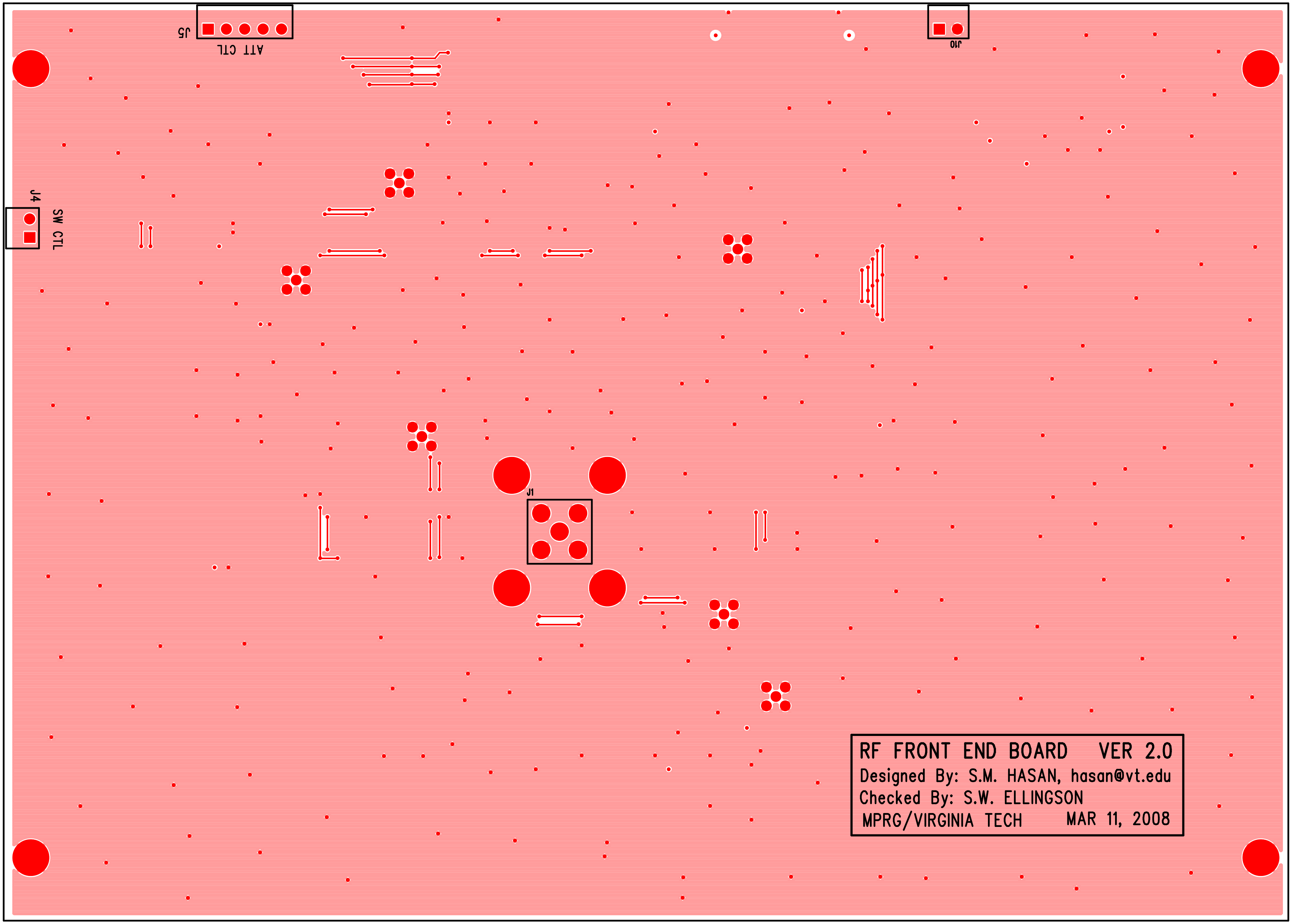
CODE:	SIZE:	DRAWING NO:	REV: 2.0

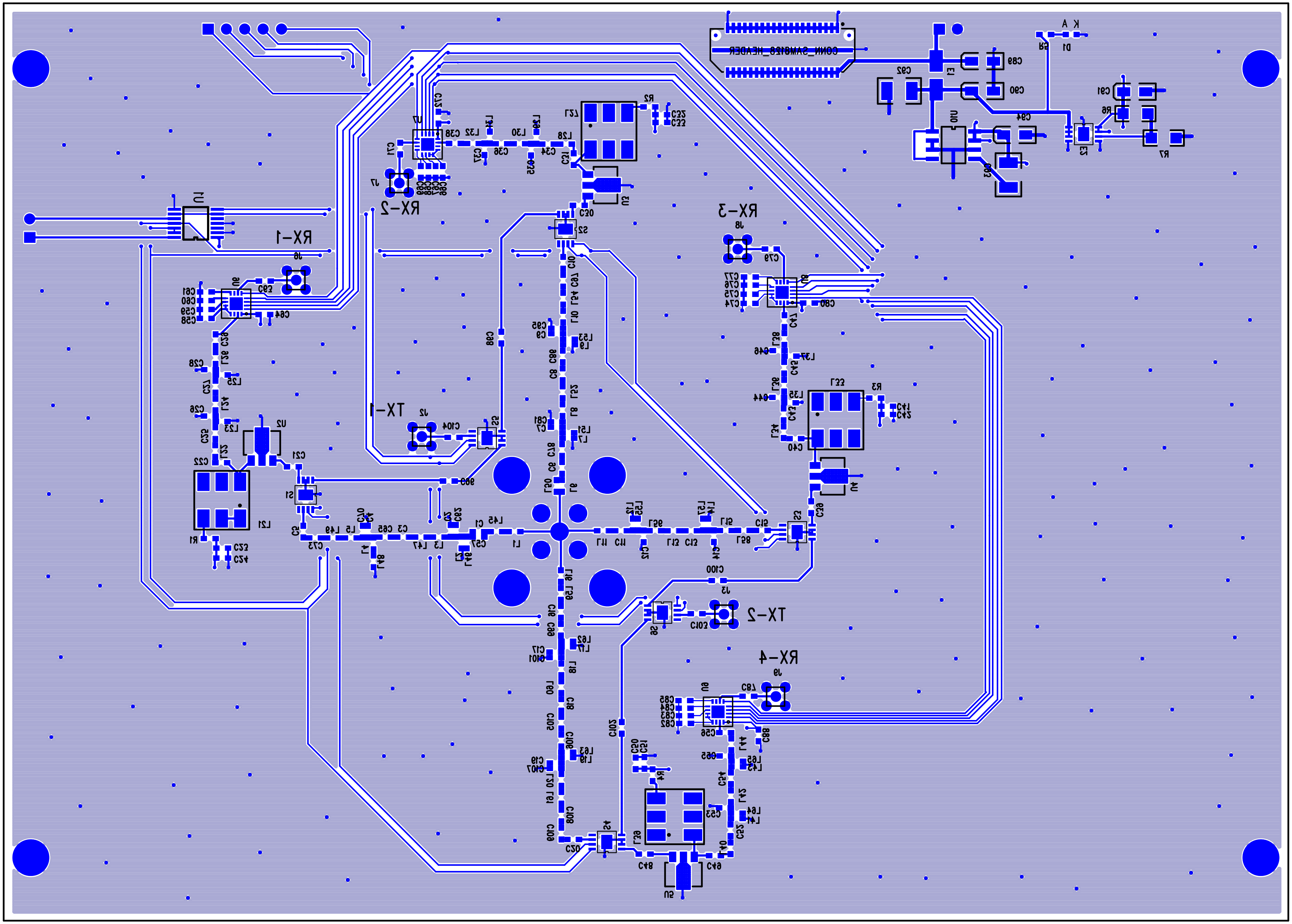
SCALE: SHEET: 4 OF 4

C Layout

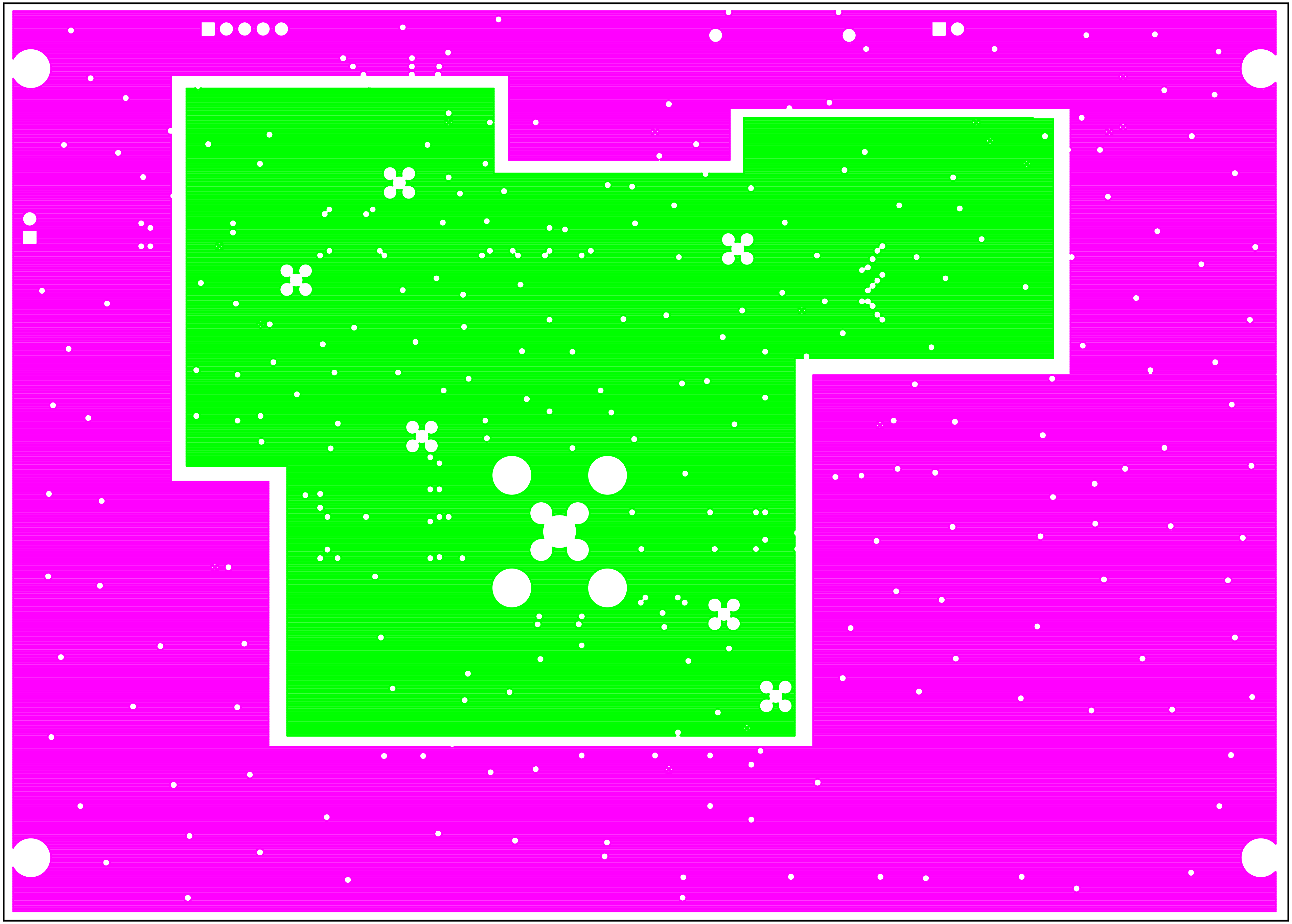
This section presents the layout and component placement of the RFFE board. The pages are added in the following order -

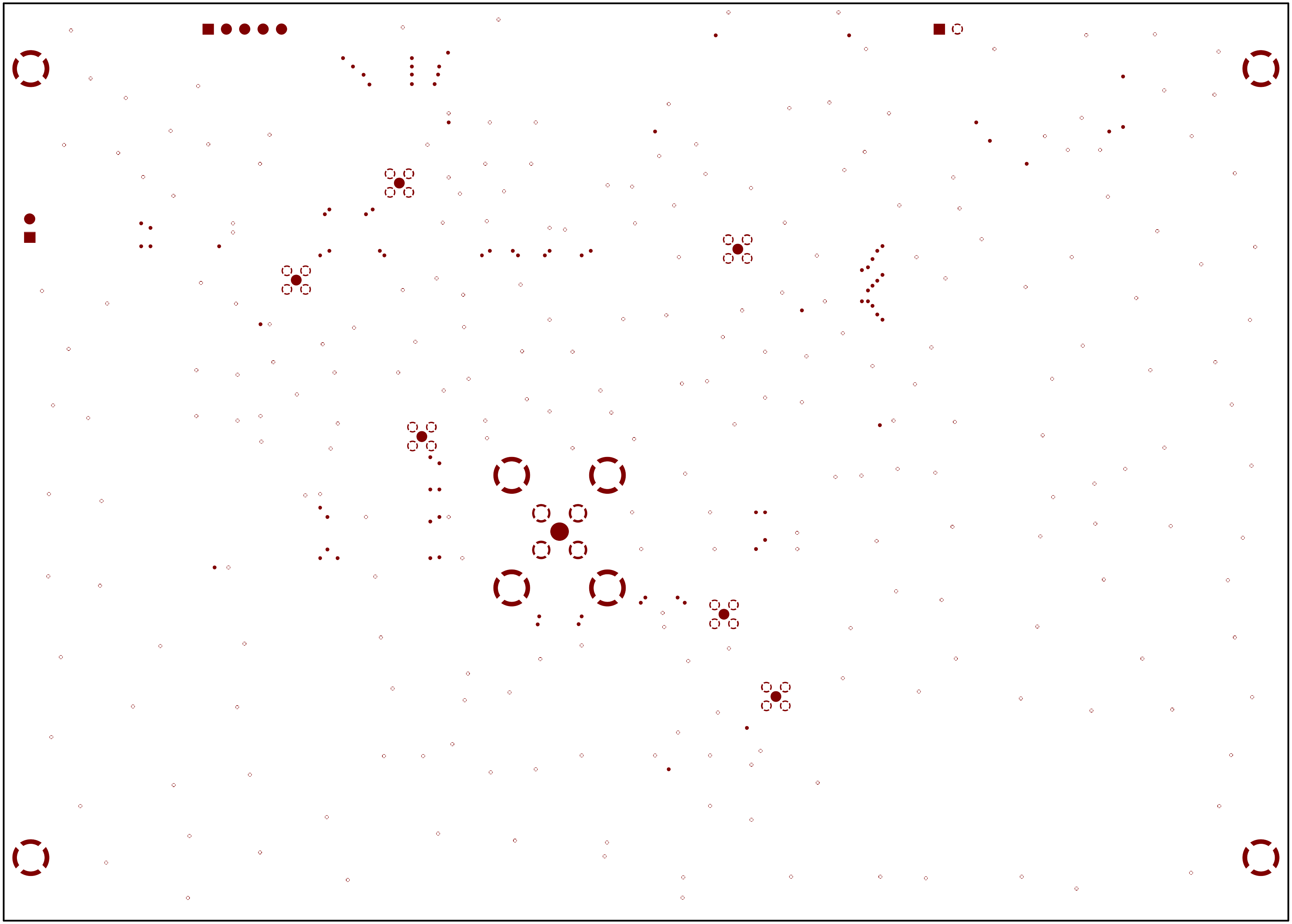
- Top layer (primary component side)
- Bottom layer (secondary component side)
- First inner layer (power layer)
- Second inner layer (ground layer)
- Component placement in top layer, and
- Component placement in bottom layer.

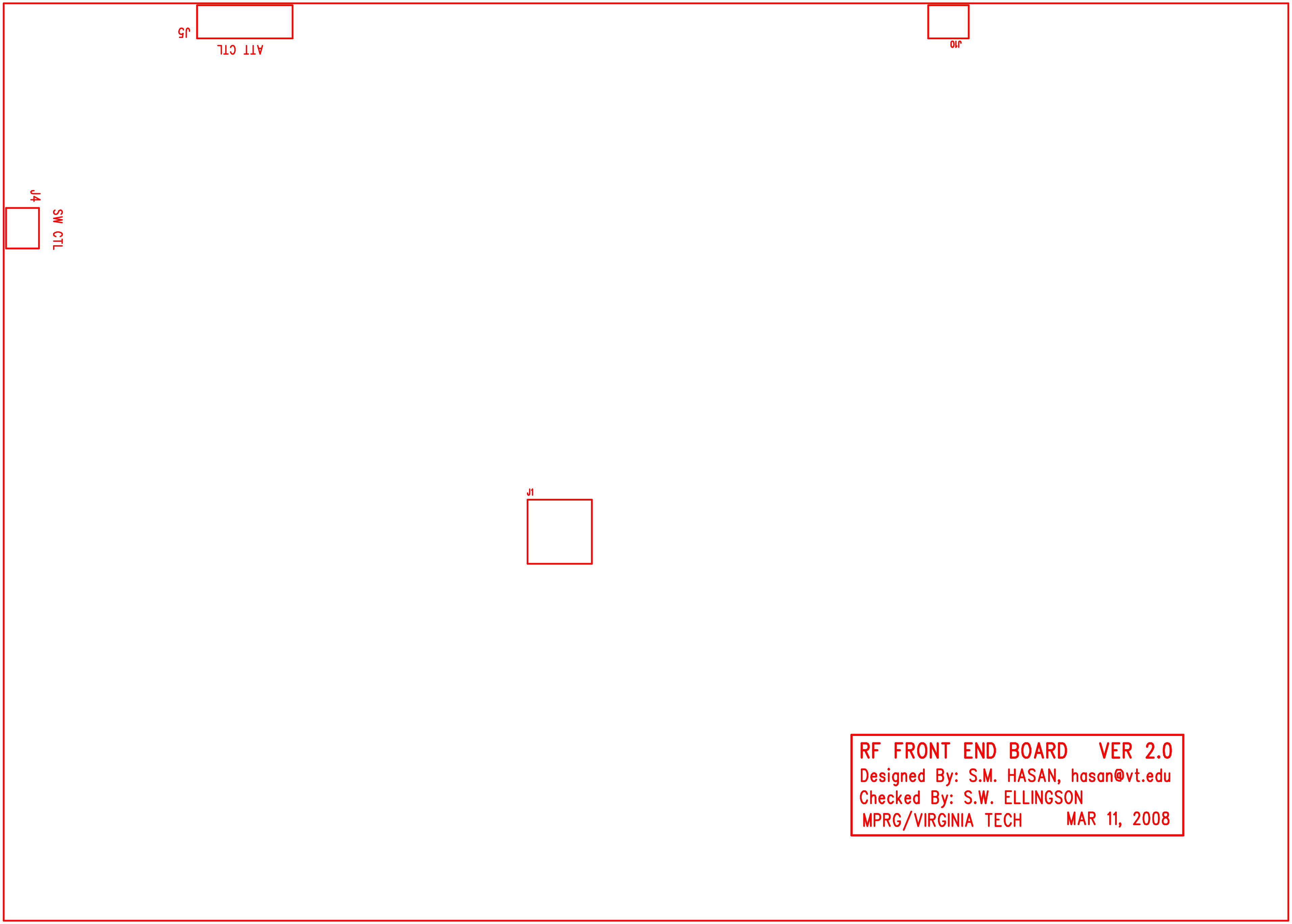

RF FRONT END BOARD VER 2.0
Designed By: S.M. HASAN, hasan@vt.edu
Checked By: S.W. ELLINGSON
MPRG/VIRGINIA TECH MAR 11, 2008
J1
J4
SW CTL
J5
ATT CTL
J10

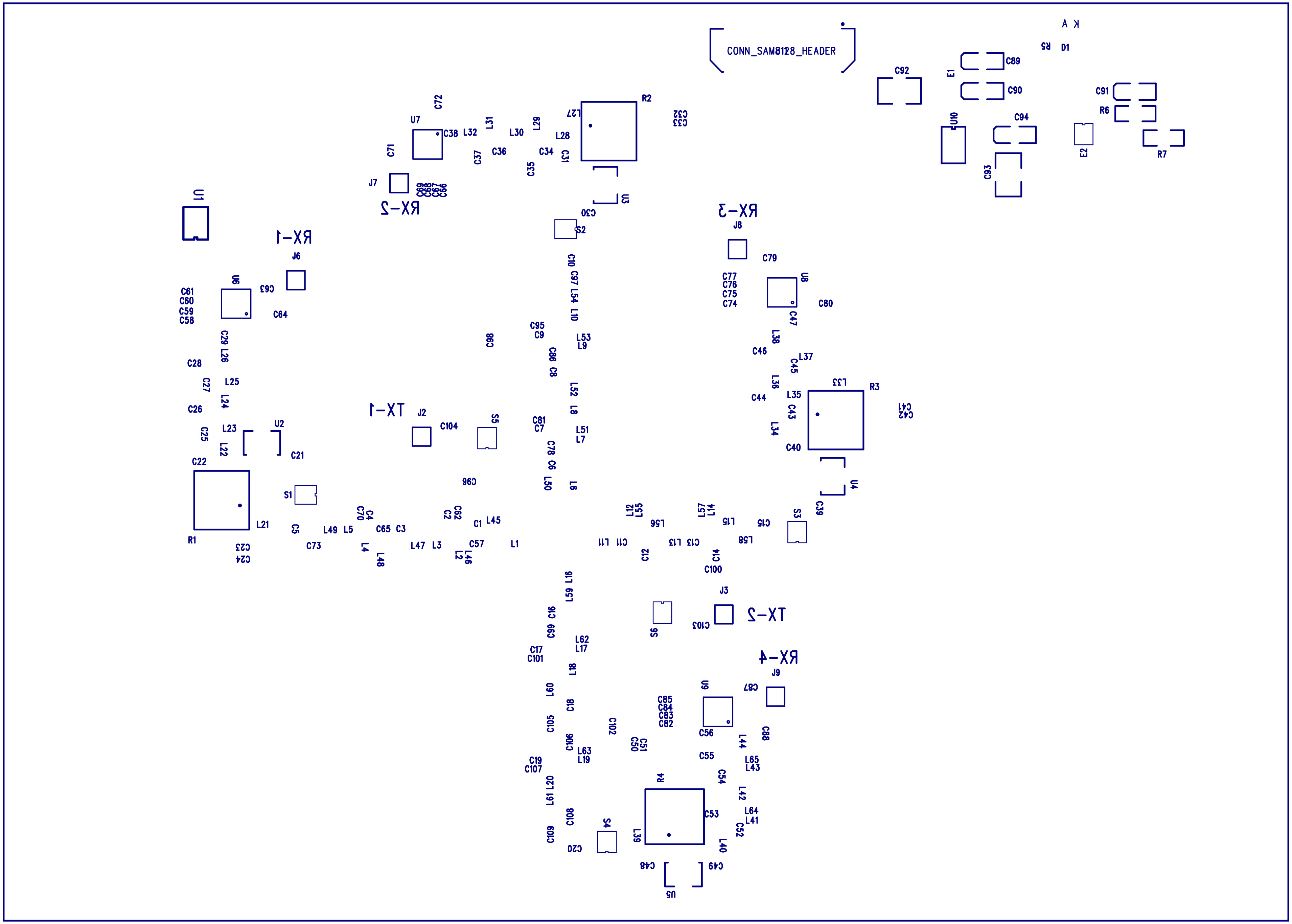


RX-1
RX-2
RX-3
RX-4
TX-1
TX-2






J5
ATT CTL
J10
J4
SW CTL
J1
RF FRONT END BOARD VER 2.0
Designed By: S.M. HASAN, hasan@vt.edu
Checked By: S.W. ELLINGSON
MPRG/VIRGINIA TECH MAR 11, 2008



CONN_SAM8128_HEADER
RX-1
RX-2
RX-3
RX-4
TX-1
TX-2