Active Array Antenna Power Supply Development Using Soft Switching Technique To Achieve High Efficiency And Better EMI/EMC Performance For Long Range Radar

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Abstract:
Active Array Antenna Power Supply is a critical system which supplies necessary DC voltages to various Line Replacement Units (LRU) of the Phased Array (T/R Modules, T/R units, Group Units, Super Group Units, Beam Forming Units). Active array for long range radar has got more than two thousands of T/R modules, more than two hundreds of T/R units which houses T/R modules and its controller. Hence more than ninety power supplies required to be designed and manufactured which are installed in the large size antenna. This antenna power supply consists of multiple types of power supplies with different voltages and wattages. As multiple voltages to be generated for different kinds of devices and components inside LRUs which offers pulsating and high inrush current loads, achieving more than 90% efficiency was challenging. Whenever power supply is designed, meeting EMI/EMC specification used to be challenging and more components have to be added in EMI/EMC circuit to meet MIL-641E Ground System requirements. Various switching topologies were considered to achieve above requirement, Soft switching technique is used for all the high power modules where the individual modules efficiency has been achieved to more than 92% and offered better EMI/EMC performance. When the power supply is tested close to actual installation configuration, it will reduce many active array integration issues which will avoid unnecessary delay in the Radar development. For this purpose ATE and HILS setup was designed and used for testing these 42 Nos of Power Supply units which made the Power supply to work without any failures and hiccups. In this paper various design aspects using soft switching, actual testing results, EMI/EMC performances and ATE are presented in detail, which led to successful completion of design and production of high efficiency active array antenna power supply units.

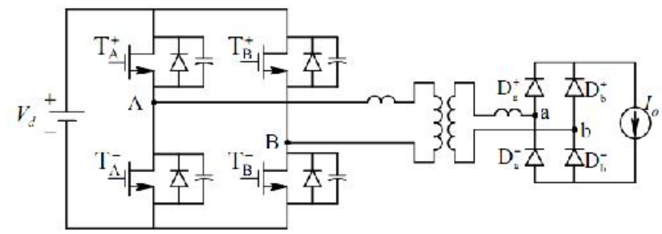
Key Words: Antenna Power Supply, DC-DC Converter, Soft Switching, ATE.

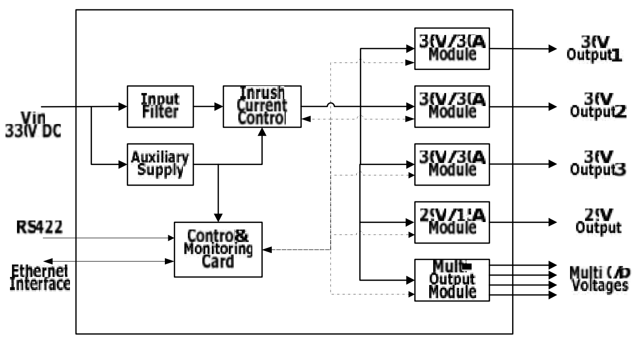
I INTRODUCTION

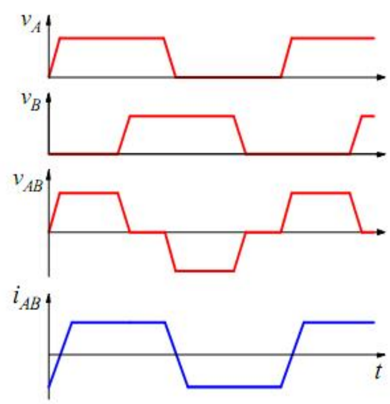
Active phased array antenna is the major system which determines the tracking accuracy of the Long Range Radar. Well known advantage of active phased array antenna is to have reliable operation of the radar even when T/R modules fail few out of thousands instead of single transmitter based antenna. Hence thousands of T/R modules and associated hundreds of T/R units, Controllers are part of the active phased array. All these above units have to be powered using highly reliable and efficient Power Supply Units (PSU). Since this is Long Range Radar which got bigger size of antenna to accommodate thousands of T/R modules, Units and Power Supplies. In this antenna 92Nos of Power Supply Units have been used, which is DC-DC converter based. It takes 330V DC input voltage from huge Rectifier System and converts it into various small output voltages required for various devices and circuits of T/R modules, T/R units and Controllers. Hence this power supply has been built in to various small DC-DC converters for better reliability and maintain-ability as joint development between LRDE and Digitronics. Since high power is used by the Radar, higher efficiency Power Supply Unit willreduce power demand of the Radar and also the reduction in demand of cooling system capacity. Various switching technique were considered which have been used in different types of power supplies. Soft Switching design technique presented in[1] provided higher efficiency is considered during design and development of the high power module in the units. Since this module has to supply peak current of the order of 240A during pulsating load, the EMI/EMC performance of the power supply was the equally more important. This soft switching technique equally found to be offering better EMI/EMC performance compared to other technique so for used. This paper presents various design and realization aspects using this switching technique. Efficiency achieved and EMI/EMC performances achieved for various voltages/modules have been presented. Since large number of power supply units have to be produced, developing the ATE which will test the power supply more close to the actual loading condition was the most necessary. A special ATE design, test results and the time saved for ATP and ESS of power supply units have been presented. Performance of the power supply in Hardware In Loop Simulation (HILS) is the main goal, which gives high confidence towards active array integration. The test results and missing parameters of the load specification have been brought out due to this HILS testing.

II ANTENNA POWER SUPPLY UNIT

Antenna Power Supply Unit mainly designed with the requirements of powering various antenna LRUs of pulsed phased array radar. Main DC output requirements are 36V/30A modules, 29V/15A, 5V/85A and Multi output modules (-30V, -5V, +7V), with efficiency of 90%. Input voltage from 12 pulse rectifier, 330V DC. EMI/EMC requirements are as per MIL461E for Ground MIL Systems. Total input power is 6kW with weight less than 25kg including the cold plate used for liquid based cooling of power supply unit. Here the critical requirements are pulse loading of 36V with I_{peak} of 240A (10% duty), and this output has to handle inrush current due to 100mF capacitance. As this power supply is for phased array antenna



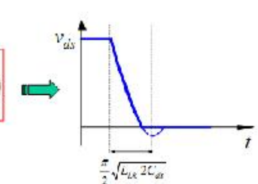




MOSFET voltage during critical turn-on transition

$$v_{ds} = V_{in} - \left(I_{mag\_pk} + I_{refl}\right)\sqrt{\frac{L_{eq}}{2C_{ds}}}\,sin(\omega t)$$

$$\omega = \frac{1}{2\pi\sqrt{L_{eq}\,C_{ds}}}$$



Conditions for ZVS

1. $\left(I_{mag\_pk} + I_{refl}\right)\sqrt{\frac{L_{eq}}{2C_{ds}}} \geq V_{in,max}$
2. $T_{delay} = \frac{\pi}{2}\sqrt{L_{eq}.2C_{ds}}$

paper [1] after their experimental power module for 1kW, it is suitable for high power applications like 36V/30A because of inherent high efficiency. As justifiedin [1], the four controlled switches (MOSFET) are considered. Commutating inductor and two low-current diodes eliminates the dynamic losses and the over shoot, and this commutating inductance also helps to ensure lossless transitions of the trailing leg of the converter.

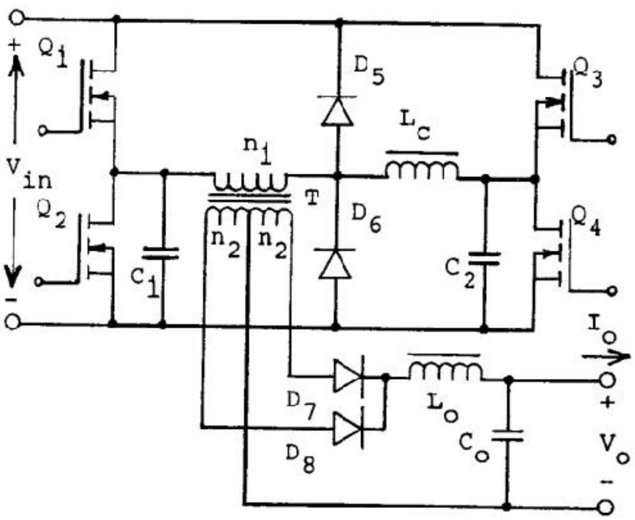


Fig.4. Full-bridge soft-switching dc/dc converter with commutating inductor and clamp diodes [1]

IV Antenna Power Supply Design

Basic principles of ZVS based full bridge converter was presented in the above section. In this section the design done using ZVS to realize the Power Supply will be presented. Also design and simulation of various control circuits used in this power supply will be presented. As shown in Fig.1. basic building blocks were designed to allocate various requirements of the power supply unit.

36V Module Design:36V module was designed and tested on the bread board. Initial test results were giving confidence with efficiency of 91% with full load. Immediately we designed the full fledged circuit which has the power circuit, control circuit, micro processor based protection and voltage-current measuring circuit. Fig.5. shows the circuit diagram of 36V/30A module.

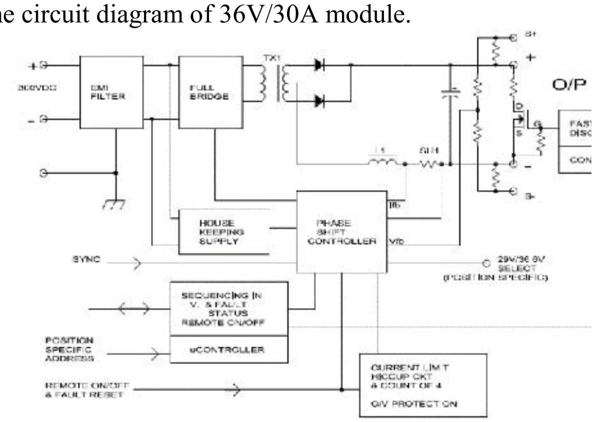


Fig.5. Schematic of 36V module

Based on the components, transformer selection, the losses were calculated as follow:

Diode	: 28 W (0.8W * 30A)
Transformer	: 20 W (10W *2)
Output Cap.	: 0.225 W
O/P Inductor	: 8 W
HKP Control	: 6 W
MOSFET	: 5 W (Conduction)
Shunt	: 0.9 W

Total losses	68.12 W.

Based on the calculated loss and output power, the calculated efficiencyis 1098W / (1098+68.12)*100 = ~ 94.55%.For another high power 29V module, the same circuit design was followed and the calculated efficiency also was in the same order.

5V Module Design: This module was designed and tested after PCB development, which has the power circuit, control circuit, micro processor based protection and voltage-current measuring circuit. This module has to deliver high current control, also branching output for three different kind of LRUs. Calculated losses as follow:

SYNC Rectifier	: 7.004 W
O/P Choke 600μOhm	: 5.86 W
MOSFET Bridge	: 0.455 W (conduction)
Output Transformer	: 5.75 * 2 = 11.5W
Shunt & house keeping	: 7.44 W

Total losses	: 32.7 W

Calculated efficiency = 442W/ (442+32.7W) x 100 =~ 93.11%. In this module, synchronous rectifier was used as it needs good regulation with high load current. Fig.6. shows the circuit diagram of 5V module, which used phase shift controller.

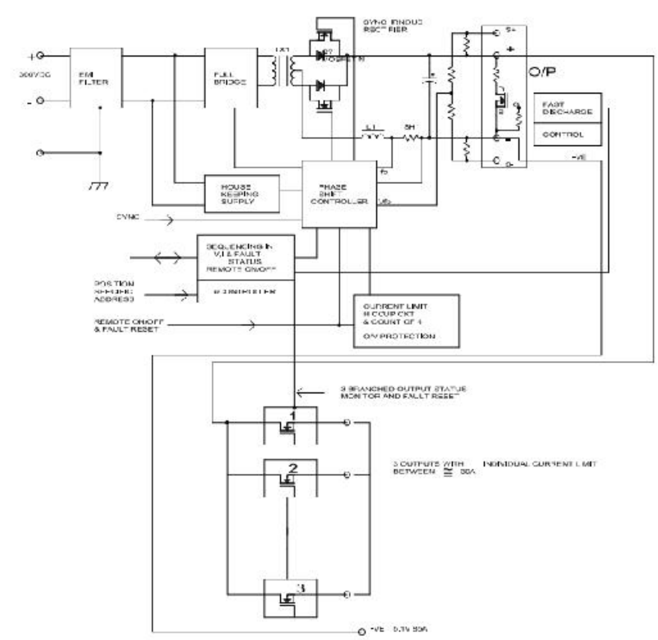
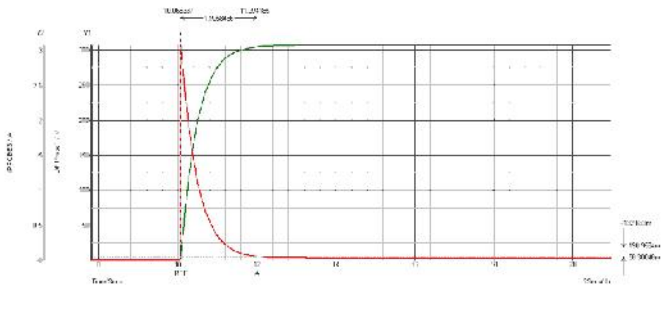
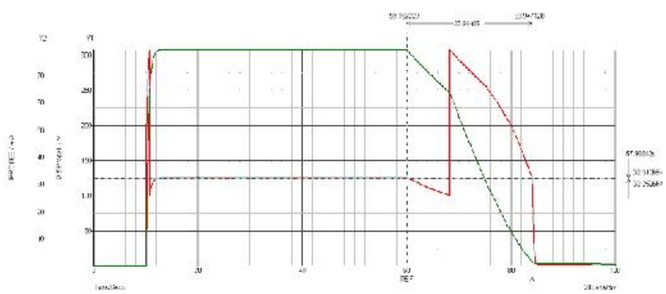


Fig.6. Schematic of 5V module





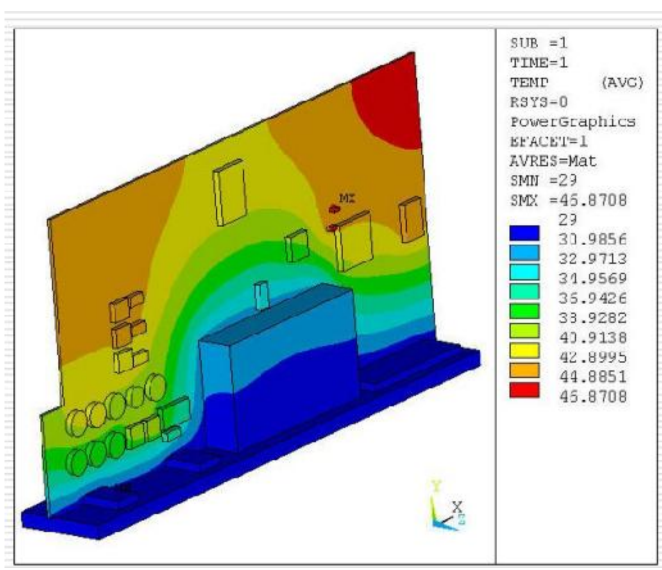

SUB =1
TIME=1
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =29
SMX =46.8708
29
30.9856
32.9713
34.9569
36.9426
38.9282
40.9138
42.8995
44.8851
46.8708
MX
Y
X

Fig.12. Photo of Module Assembly of Power Supply Unit

Table 1. Full load Efficiency with LPRF load:

```
$### [DIGITRONICS_R3/ANT/ALRU-PSU_Diagnostic_Data] ###}
{[S/N:001] [M/N:D5617-A1] [P/N:1033-600-001] [S/N:001]}
{[MODE=(1)ONN_Network      ],[7 BIT ADDRESS(LRUID)=001]}
{#STATUS#|7Bit Table= 0x001 4Bit Differntial= 0b0000 |}
{|O/P |I/P | GU |Temperature|TRU1|TRU2|Capacitor|Sync|}
{| OK | OK | OK |     OK    | OK | OK |    OK   | OK |}
{######## [Branch/Module_Status_Definitions] #########}
{Status8(n)= Internal Communication Status-----------!}
{Status7(c)= Capacitor Failure Status---------------!|}
{Status6(h)= Over Temperature (>= +90 C)-----------! |}
{Status5(t)= Over Temperature (>= +80 C)----------!| |}
{Status4(v)= Over Voltage  Status----------------!|| |}
{Status3(i)= Over Current/Load Status-----------!||| |}
{Status2(b)= Branch On/Off Status--------------!|||| |}
{Status1(m)= Module On/Off Status-------------!||||| |}
{######### [Indivisual_Branch_Status] ########|||||| |}
{XX[Branch Type] Voltage Curr. Power    Temp. mbivthcn}
{A1[+36.6vATRU1] +36.60V 22.4A 0819.83W +44 C --------}
{A2[+36.6vATRU2] +35.60V 21.7A 0794.21W +37 C --------}
{B1[+36.6vBTRU1] +35.60V 21.8A 0797.87W +37 C --------}
{B2[+36.6vBTRU2] +36.60V 22.0A 0805.19W +36 C --------}
{C3[+29.0v, GU ] +29.00V 10.7A 0310.29W +30 C --------}
{D1[+07.0v,TRU1] +06.99V 03.7A 0025.86W +51 C --------}
{D2[+07.0v,TRU2] +07.00V 04.1A 0028.69W +51 C --------}
{D3[+07.0v, GU ] +06.99V 03.6A 0025.16W +51 C --------}
{E1[+05.1v,TRU1] +05.08V 28.6A 0145.28W +33 C --------}
{E2[+05.1v,TRU2] +05.10V 28.5A 0145.34W +33 C --------}
{E3[+05.1v, GU ] +05.09V 28.1A 0143.02W +33 C --------}
{F1[+15.0v,TRU1] +15.06V 01.6A 0024.09W +51 C --------}
{F2[+15.0v,TRU2] +15.08V 01.7A 0025.63W +51 C --------}
{F3[+15.0v, GU ] +15.06V 01.6A 0024.09W +51 C --------}
{G1[-05.2v,TRU1] -05.26V 01.7A 0008.94W +51 C --------}
{G2[-05.2v,TRU2] -05.27V 01.7A 0008.95W +51 C --------}
{G3[-05.2v, GU ] -05.26V 01.7A 0008.94W +51 C --------}
{H1[-30.0v,TRU1] -30.20V 01.6A 0048.32W +51 C --------}
{H2[-30.0v,TRU2] -30.20V 01.7A 0051.34W +51 C --------}
{H3[-30.0v, GU ] -30.20V 01.7A 0051.34W +51 C --------}
{######[Input_Filter_Status_Definitions]#####   ___vthcn}
{Status3(u)= I/P Under  Voltage >= 2.5 sec------!|||| |}
{Status2(s)= I/P Under  Voltage Detected-------!||||| |}
{Status1(k)= I/P Normal Voltage Status--------!|||||| |}
{##[Input_Status]#######[Capacitor=4500uF]### ksuvthcn}
{IF[InputFilter] +0309V +15.0A 4635.00W +30 C --------}
{Power [I/P= 4635.02W,O/P=4292.50W] Efficiency= 92.61%}
{## IPV4=128.127.6.1       ### MAC= 00:90:E8:3C:9D:84 ##@
```

Table 2. Full load Efficiency with Static load:

```
$### [DIGITRONICS_R3/ANT/ALRU-PSU_Diagnostic_Data] ###}
{[S/N:001] [M/N:D5617-A1] [P/N:1033-600-001] [S/N:001]}
{[NODE=(1)ONN_Network      ],[7 BIT ADDRESS(LRUID)=001]}
{#STATUS#|7Bit Table= 0x001 4Bit Differntial= 0b0000 |}
{|O/P |I/P | GU |Temperature|TRU1|TRU2|Capacitor|Sync|}
{| OK | OK | OK |     OK    | OK | OK |    OK   | OK |}
{######## [Branch/Module_Status_Definitions] #########}
{Status8(n)= Internal Communication Status-----------!}
{Status7(c)= Capacitor Failure Status---------------!|}
{Status6(h)= Over Temperature (>= +90 C)-----------!||}
{Status5(t)= Over Temperature (>= +80 C)----------!|||}
{Status4(v)= Over Voltage  Status----------------!||||}
{Status3(i)= Over Current/Load Status-----------!|||||}
{Status2(b)= Branch On/Off Status--------------!||||||}
{Status1(m)= Module On/Off Status-------------!|||||||}
{######### [Indivisual_Branch_Status] ########||||||||}
{XX[Branch Type] Voltage Curr. Power    Temp. mbivthcn}
{A1[+36.6vATRU1] +36.60V 30.0A 1098.00W +52 C --------}
{A2[+36.6vATRU2] +36.60V 29.7A 1087.02W +43 C --------}
{B1[+36.6vBTRU1] +36.60V 29.6A 1083.35W +43 C --------}
{B2[+36.6vBTRU2] +36.60V 29.9A 1094.33W +40 C --------}
{C3[+29.0v, GU ] +29.00V 15.0A 0435.00W +28 C --------}
{D1[+07.0v,TRU1] +06.99V 05.0A 0034.95W +49 C --------}
{D2[+07.0v,TRU2] +07.00V 05.0A 0035.00W +49 C --------}
{D3[+07.0v, GU ] +06.99V 04.9A 0034.25W +49 C --------}
{E1[+05.1v,TRU1] +05.08V 28.5A 0144.77W +32 C --------}
{E2[+05.1v,TRU2] +05.11V 28.4A 0145.12W +32 C --------}
{E3[+05.1v, GU ] +05.09V 28.1A 0143.02W +32 C --------}
{F1[+15.0v,TRU1] +15.06V 01.6A 0024.09W +49 C --------}
{F2[+15.0v,TRU2] +15.08V 01.7A 0025.63W +49 C --------}
{F3[+15.0v, GU ] +15.08V 01.6A 0024.12W +49 C --------}
{G1[-05.2v,TRU1] -05.26V 01.7A 0008.94W +49 C --------}
{G2[-05.2v,TRU2] -05.26V 01.7A 0008.94W +49 C --------}
{G3[-05.2v, GU ] -05.26V 01.7A 0008.94W +49 C --------}
{H1[-30.0v,TRU1] -30.20V 01.6A 0048.32W +49 C --------}
{H2[-30.0v,TRU2] -30.20V 01.7A 0051.34W +49 C --------}
{H3[-30.0v, GU ] -30.20V 01.7A 0051.34W +49 C --------}
{######[Input_Filter_Status_Definitions]#####   ___vthcn}
{Status3(u)= I/P Under  Voltage >= 2.5 sec------!||||||}
{Status2(s)= I/P Under  Voltage Detected-------!|||||||}
{Status1(k)= I/P Normal Voltage Status--------!||||||||}
{##[Input_Status]#######[Capacitor=4500uF]### ksuvthcn}
{IF[InputFilter] +0308V +19.7A 6067.60W +32 C --------}
{Power [I/P= 6067.60W,O/P=5586.53W] Efficiency= 92.07%}
{## IPV4=128.127.6.1       ### MAC= 00:90:E8:3C:9D:84 ##@
```

EFFICIENCY RESULTS: The main goal of developing high efficiency power supply was achieved which was seen in the test results of the Qualification unit. The above tables show the full load efficiency as measured by the ATE for static load and pulsating load conditions. Full load efficiency for LPRF measured was 92.6%, the individual module efficiency measured during internal testing was 93.4% also for 36V module. Full load efficiency for static load measured was 92.07%. This measured result is almost close to the estimated efficiency. The Table 1 and Table 2 show the GUI screen shot of measured values of voltage, current and efficiency of first unit (S/N:1).

EMI/EMC RESULTS: All the tests were done as per MIL 461E standard at LRDE, EMI/EMC test facility. The performance results were within the limits and power supply found working satisfactorily. Since input voltage is 300V DC, the limit line relaxed by 10dB for CE102 test. Following figures show the CE102 result of first unit.CS101, CS114, CS115, CS116, RE 102 and RS103 were done and the results met the requirements successfully.

Fig.13. MODEL D5898, Digitronics 300VDC Positive Line CE102

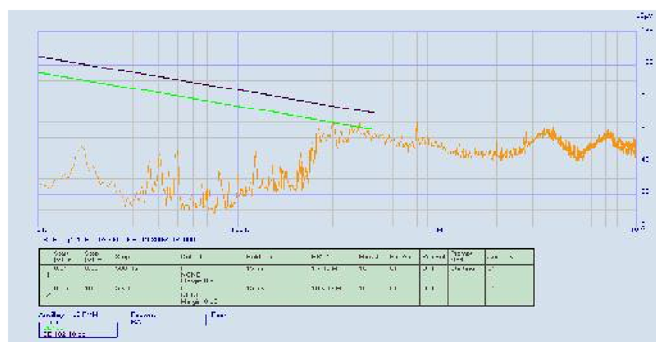


Fig.14. MODEL D5898, Digitronics 300VDC Negative Line CE102

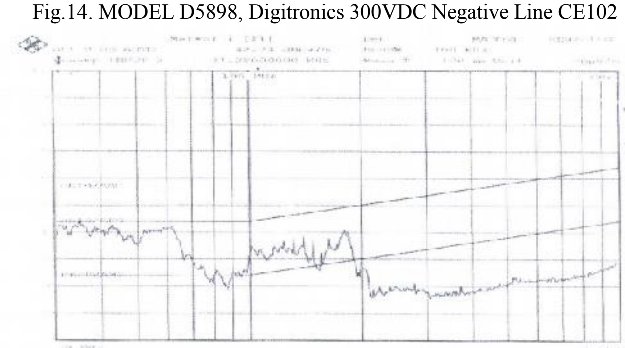
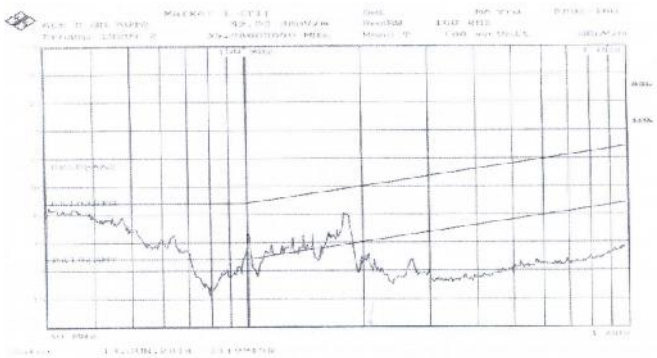
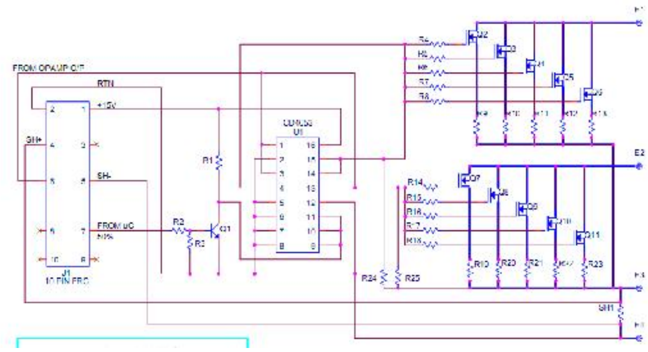
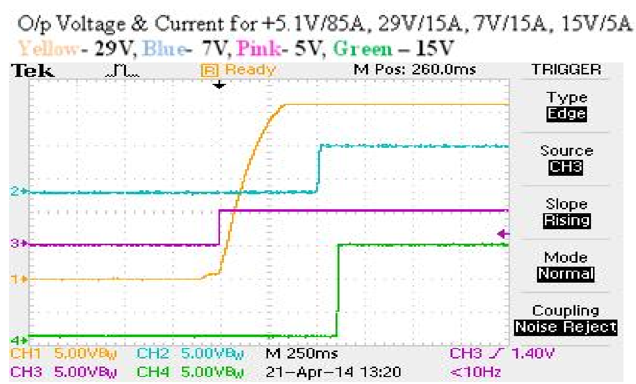
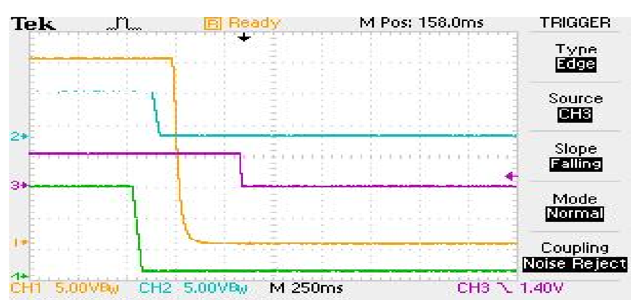


Fig.15. RE Electric Field 30MHz to 1 GHz, VP

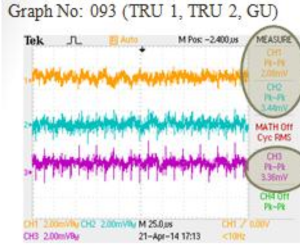



FROM OPAMP O/P
RTN
+15V
SH+
SH-
FROM uC
U1
R1
R2
R3
Q1
R24
R25
E2

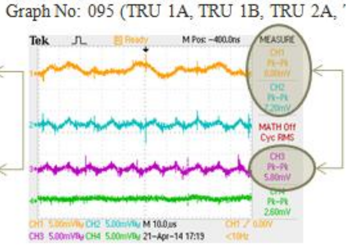

O/p Voltage & Current for +5.1V/85A, 29V/15A, 7V/15A, 15V/5A
Yellow- 29V, Blue- 7V, Pink- 5V, Green – 15V
Tek
Ready
M Pos: 260.0ms
TRIGGER
Type Edge
Source CH3
Slope Rising
Mode Normal
Coupling Noise Reject
CH1 5.00V CH2 5.00V M 250ms CH3 1.40V
CH3 5.00V CH4 5.00V 21–Apr–14 13:20 <10Hz


Tek
Ready
M Pos: 158.0ms
TRIGGER
Type Edge
Source CH3
Slope Falling
Mode Normal
Coupling Noise Reject
CH1 5.00V CH2 5.00V M 250ms CH3 1.40V
CH1 vertical position −2.76 divs (−13.8V)

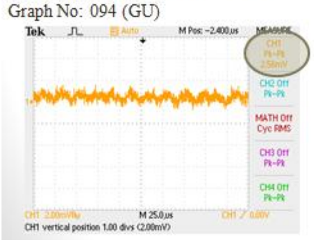
O/p Voltage & Current for +5.1V/28.33A
Graph No: 093 (TRU 1, TRU 2, GU)



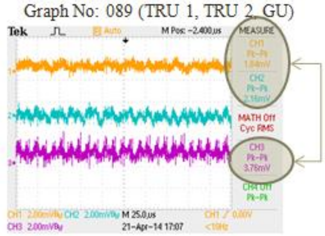
O/p Voltage & Current for +36.6V/30A
Graph No: 095 (TRU 1A, TRU 1B, TRU 2A, '



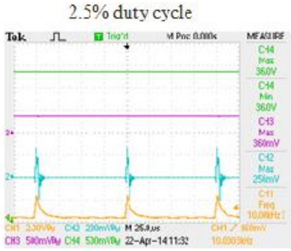
O/p Voltage & Current for 29V/15A
Graph No: 094 (GU)



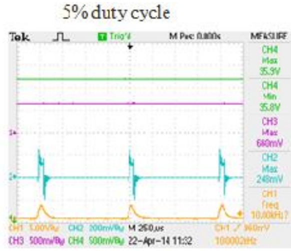
O/p Voltage & Current for -5.2V/1.66A
Graph No: 089 (TRU 1, TRU 2, GU)



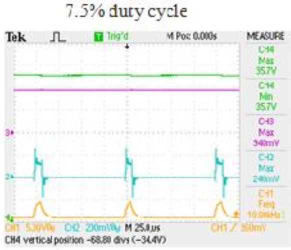
2.5% duty cycle



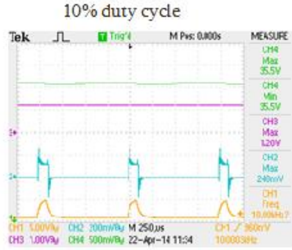
5% duty cycle



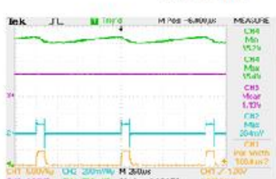
7.5% duty cycle



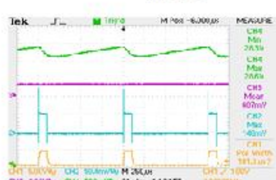
10% duty cycle



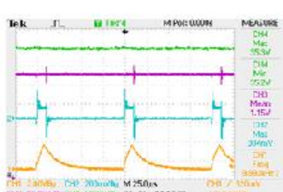
36.5V/240A



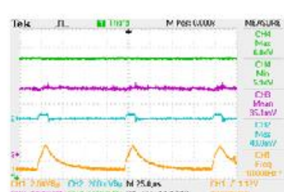
7V/40A

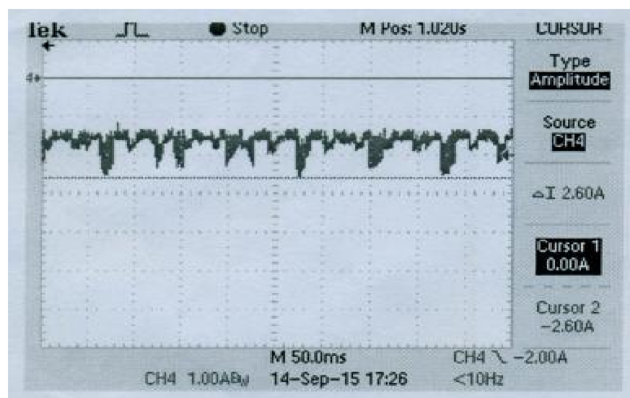


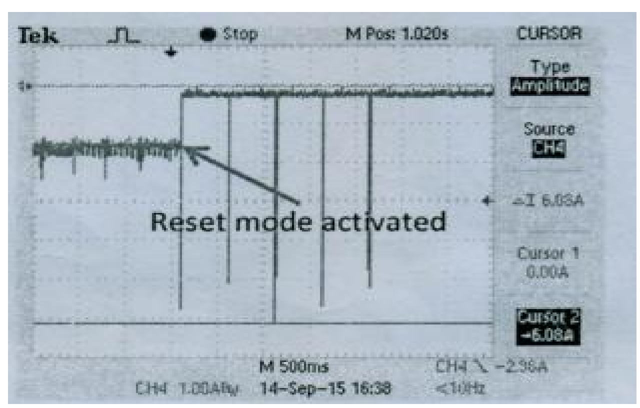
36.6V/240A



+7V/40A

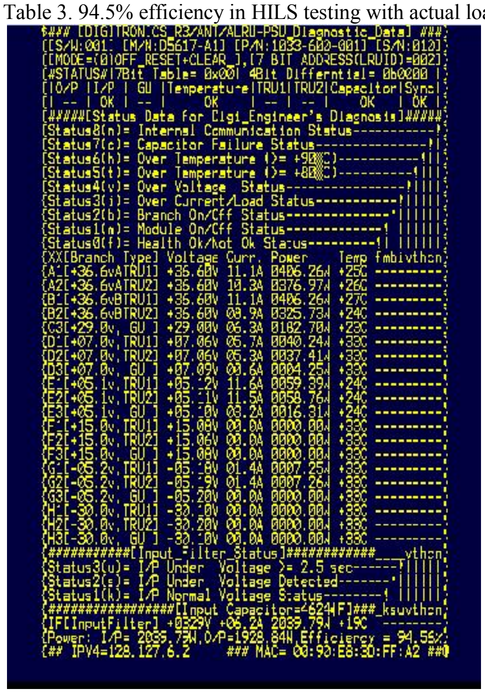






Tripping of -5V during Radar reset mode could only be identified because of HILS. After tripping issue, proper studies correction was done. And also various other configurations of radar operation was tested and found PSU working normal. Also the 8hours endurance test result in HILS which is shown in Table 3 brings out the actual current consumption and the efficiency of 94% achieved during the testing. Here the actual load current value is half of the designed value, as the PSU has been designed to take care of future requirements and de-rating factor to increase the reliability of the PSU. With this method, before more than 200LRUs to be installed and integrated with total PSUs in the Active Array Antenna, the problems are identified and corrected. This saved significant time in the Radar assembly and integration.

Table 3. 94.5% efficiency in HILS testing with actual load



```
$### [DIGITRON.CS_R3/ANT/ALRU-PSU_Diagnostic_Data] ###;
[[S/W:001] [M/N:D5617-A1] [P/N:1033-600-001] [S/N:012];
[[MODE=(0)OFF_RESET+CLEAR_],[7 BIT ADDRESS(LRUID)=002];
[#STATUS#|7Bit Table= 0x00| 4Bit Differntial= 0b0000 |;
[|0/P |I/P | GU |Temperature|TRU1|TRU2|Capacitor|Sync|;
[| -- | OK | -- |    OK     | -- | -- |   OK    | OK |;
[#####[Status Data for Digi_Engineer's Diagnosis]#####;
[Status8(n)= Internal Communication Status-----------!;
[Status7(c)= Capacitor Failure Status---------------!|;
[Status6(h)= Over Temperature (>= +90 C)-----------!||;
[Status5(t)= Over Temperature (>= +80 C)----------!|||;
[Status4(v)= Over Voltage  Status----------------!||||;
{Status3(i)= Over Current/Load Status-----------!|||||;
{Status2(b)= Branch On/Off Status--------------'||||||;
{Status1(m)= Module On/Off Status-------------! ||||||;
{Status0(f)= Health Ok/Not Ok Status---------!| ||||||;
{XX[Branch Type] Voltage Curr. Power    Temp fmbivthcn;
{A1[+36.6vATRU1] +35.60V 11.1A 0406.26W +25C ---------;
{A2[+36.6vATRU2] +35.60V 10.3A 0376.97W +26C ---------;
{B1[+36.6vBTRU1] +35.60V 11.1A 0406.26W +27C ---------;
{B2[+36.6vBTRU2] +35.60V 08.9A 0325.73W +24C ---------;
{C3[+29.0v, GU ] +29.00V 06.3A 0182.70W +23C ---------;
{D1[+07.0v,TRU1] +07.06V 05.7A 0040.24W +33C ---------;
{D2[+07.0v,TRU2] +07.06V 05.3A 0037.41W +33C ---------;
{D3[+07.0v, GU ] +07.09V 00.6A 0004.25W +33C ---------;
{E1[+05.1v,TRU1] +05.12V 11.6A 0059.39W +24C ---------;
{E2[+05.1v,TRU2] +05.11V 11.5A 0058.76W +24C ---------;
{E3[+05.1v, GU ] +05.10V 03.2A 0016.31W +24C ---------;
{F1[+15.0v,TRU1] +15.08V 00.0A 0000.00W +33C ---------;
{F2[+15.0v,TRU2] +15.06V 00.0A 0000.00W +33C ---------;
{F3[+15.0v, GU ] +15.08V 00.0A 0000.00W +33C ---------;
{G1[-05.2v,TRU1] -05.18V 01.4A 0007.25W +33C ---------;
{G2[-05.2v,TRU2] -05.19V 01.4A 0007.26W +33C ---------;
{G3[-05.2v, GU ] -05.20V 00.0A 0000.00W +33C ---------;
{H1[-30.0v,TRU1] -30.10V 00.0A 0000.00W +33C ---------;
{H2[-30.0v,TRU2] -30.20V 00.0A 0000.00W +33C ---------;
{H3[-30.0v, GU ] -30.10V 00.0A 0000.00W +33C ---------;
{###########[Input_Filter_Status]###########____vthcn;
{Status3(u)= I/P Under  Voltage >= 2.5 sec------!|||||;
{Status2(s)= I/P Under  Voltage Detected-------'||||||;
{Status1(k)= I/P Normal Voltage Status--------! ||||||;
{#################[Input Capacitor=4624uF]###_ksuvthcn;
{IF[InputFilter] +0329V +06.2A 2039.79W +19C ---------;
{Power: I/P= 2039.79W,O/P=1928.84W,Efficiency = 94.56%;
{## IPV4=128.127.6.2     ### MAC= 00:90:E8:30:FF:A2 ##
```

CONCLUSION

Antenna Power Supply Units have been designed and produced in large numbers as joint development effort between LRDE and Digitronics. As this PSU has to supply many voltages, realizing the multiple modules with Ethernet interface for online monitoring was achieved first time by Digitronics with LRDE guidance. We used the soft switching technique to design and realize antenna power supply with high efficiency for high power applications. We have achieved full load efficiency of 92% close to the calculated efficiency, and also achieved 94.5% in the HILS testing, where PSU works with half load. This is highest efficiency achieved for customized power supply development for any radar development in LRDE. Being long range radar, this achievement in high efficiency will bring down the power consumption of the radar to significant percentage, which will be verified shortly when the Radar testing completes. Also the EMI/EMC performance was better and met the requirements as per MIL 461E. Developing the ATE with full fledged capability to test the PSU for all the working conditions was an achievement. This ATE helped in reducing the production time, also it will be useful in the Radar operational site to identify the faults and replace the faulty modules. So that only faulty module will be sent to the factory for D level repair instead of sending the PSU. LRDE shall follow the system engineering practices followed in this project for the development of the power supply of future Radars.

ACKNOWLEDGEMENT

Antenna Power Supply Units development and production in large numbers happened successfully with the support of Mechanical Expert Mr. S Mani, LRDE, QA Expert Mr VR Prakash Babu, LRDE, production team of Digitronics, integration support from Jai Sales Corporation and inspection support from BEL, Bangalore. We thank them for their support to achieve the successful completion of this project.

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[2] Ned Mohan, Rajapandian Ayyanar, E Persson "Soft Switching in DC-DC Converters: Principles, Practical Topologies", *APEC 2002*.

[3] Rajapandian Ayyanar, Ned Mohan "Novel Soft-Switching DC-DC Converter with Full ZVS-Range and Reduced Filter Requirement – Part I:Regulated-Output Applications",*IEEE Transactions On Power Electronics, VOL.16, NO. 2, March 2001,Page:184-192.*

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Vijay V.Damle graduated from College of Engineering Pune in 1963 and received M.Sc Engineering in 1964. In 1965, he won the prestigious Hindu Hitachi scholarship and studied in various factories of Hitachi in Japan for one year. On return, he started a company in partnership to manufacture linear power supplies. In 1975, he started his own company Digitronics in Pune. Products include high wattage power switched mode supplies for radars, jammers, pulsed power supplies for nuclear research, power supplies for railways and special purpose ATEs etc. Digitronics always tries to use the latest technologies to make better products.

Nandakumar S received his B.E. degree in Electrical and Electronics engineering from Bharathiar University, Coimbatore and M.Tech degree in Electronic systems from Indian Institute of Technology, Bombay. He has been working as Scientist in LRDE, Bangalore, since 2000. His areas of working are Radar Power System, Radar Systems Automation, and Radar System Engineering.

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