Improved LNB Power Circuit Design for Enhanced Reliability by Current Limiting Control

Cansel Sahin, Gokturk Poyrazoglu and Ismail Yilmazlar

October 9, 2023

Improved LNB Power Circuit Design for Enhanced Reliability by Current Limiting Control

1st Cansel Sahin
Dep. of HW Design in TV Systems
Vestel Electronic
Manisa, Turkey
cansel.sahin@vestel.com.tr

2nd Gokturk Poyrazoglu
Dep. of Electrical Electronics Engineering
Ozyegin University
İstanbul, Turkey
gokturk.poyrazoglu@ozyegin.edu.tr

3rd Ismail Yilmazlar
Dep. of HW Design in TV Systems
Vestel Electronic
Manisa, Turkey
ismail.yilmazlar@vestel.com.tr

***Abstract*—Low Noise Block (LNB) circuits are an essential component of satellite receiving systems in televisions. LNB converts high-frequency satellite signals into a lower frequency range for transmission to the receiver. Also, LNB ensures low-noise signal reception, enables polarization control, supports multiple frequency bands, and amplifies signals. The LNB power circuits provide power to the LNB. Voltage-controlled boost converters are commonly used in these circuits; the current limiting feature used in these circuits can be insufficient to handle sudden current spikes, leading to feedback from end users. They are not immune to short circuits because of installation problems with satellite cables, which are a common failure mode that potentially damages the LNB power or other components in the television, resulting in a loss of satellite signal. Hence, leading to a poor user experience and harming the manufacturer's reputation. Replacing a damaged LNB power circuit is also difficult because it is often integrated into the TV's design and is not easily replaceable. To mitigate this problem, a parallel resonant converter approach is introduced that limits the output current up to a pre-defined level by frequency control, which provides an alternative to voltage-controlled boost converters. Parallel resonant converter circuits operate as current sources so maximum current cannot exceed this defined operation frequency point under any circumstances. In this study, the mathematical equations of the proposed circuit were obtained, and then the operating conditions were determined. The operation frequency ranges were interpreted graphically using Matlab, and the parallel resonant converter design was evaluated using simulation model by using MATLAB's Simulink Toolbox. These results show that the parallel resonant converter approach maintaining a stable current and reducing the risk of short circuit damage. The proposed design is expected to reduce repair costs due to LNB power circuits for TV manufacturers.**

***Keywords*—Parallel resonant converter, low noise block power, satellite systems.**

I. INTRODUCTION

Television broadcasting under Digital Broadcast Satellite (DVBS) regulations is one of the most popular consumer applications [1]. The Low Noise Block (LNB) circuit is a component of satellite systems and is a converter that connects to the satellite antenna. This circuit receives very high-frequency signals from the satellite and converts these signals to a lower frequency [2]. Figure 1 shows that, a satellite receiver captures the radio frequency (RF) signal that is transmitted from a satellite antenna. The signal is then sent to the LNB Down-converter circuitry on the antenna, which converts the signal to a lower frequency intermediate frequency (IF) signal [3]. The IF signal is then sent to the demodulation chip inside the satellite receiver, which demodulates the signal and converts it back to the original digital signal. The LNB power supply is a crucial part of satellite communication systems and plays a big role in TV signals are broadcast according to Digital Broadcast Satellite (DVBS) rules. Inside satellite setups, the Low Noise Block (LNB) circuit, which works like a converter and connects to the satellite antenna, relies on the LNB power supply to work properly. In simpler terms, the LNB power supply is responsible for delivering the essential electrical power that enables the proper functioning and operation of the LNB circuit. The LNB power circuit usually consists of a regular DC power supply and provides the required power voltage to the LNB. The LNB requires 13V and 18V supply voltages that can operate, where the 13V is used to adjust the LNB polarization horizontally, while the 18V is used for vertical polarization adjustment. These voltages are controlled by the satellite receiver, which sends the appropriate voltage to the satellite antenna. LNB power circuits are usually built with boost DC/DC converter circuits that have voltage control. [4] The proposed LNB power circuit was designed using the capabilities provided by parallel resonant DC/DC converters, which offer high efficiency, low noise levels, and current limitation up to 500mA, with the required 13V/18V operating frequencies being determined. In this circuit, the current at the output is calculated by considering the load changes at the output. The calculated output current is transmitted to the frequency control circuit, making the necessary frequency

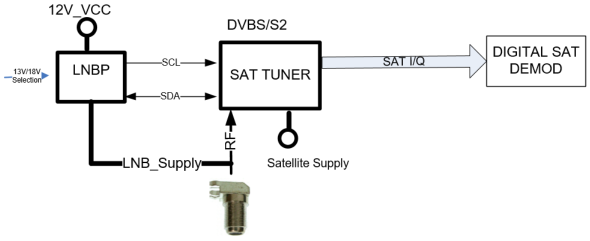


Fig. 1: The Block Diagram of the Digital Broadcast Satellite

adjustment to limit the current. The circuit is designed to limit the current to a maximum of 500mA by using frequency control. In this way, it is aimed to minimize the short circuit problems experienced during the wiring problems of the TV users.

II. PROPOSED CIRCUIT

Figure 2 shows the proposed parallel resonant converter circuit. 2 mosfets S1 and S2 form a half-bridge converter. The full bridge rectifier circuit consists of four diodes D1, D2, D3, and D4. Inductor L_r and capacitor C_r are used to create an oscillation in the circuit and to ensure that this oscillation continues at the desired frequency and waveform. Lout and Cout are represented as output filters that minimize fluctuations in the output voltage and current, providing the desired smooth output voltage and current.

A. Parallel resonant Converter Operating

The parallel resonant DC/DC converter circuit is operated at a fixed %50 duty cycle with frequency control according to the output current. The circuit described starts with applying a square wave voltage VAB, controlled by switches, to a desired parallel resonant circuit. When the voltage is in the correct polarity, it creates a magnetic field in the inductor, storing energy in the capacitor. Once the magnetic field is established, the circuit allows the energy to discharge from the capacitor to the inductor, creating a sinusoidal voltage at a resonant frequency, which is called VCB. This voltage is rectified and filtered, resulting in a current Iout. So, when VCB is positive, the output of the current takes a positive value of Iout, otherwise, VCB is negative, and the output of the current takes a negative value of Iout. The average value of the square wave voltage of the bridge (VCB) is equal to the output voltage, assuming that the voltage across the C_r capacitor is sinusoidal.

The features of the proposed LNB power circuit design are as follows:

- The proposed circuit limits the current and prevents short circuits that may occur in satellite cable installations.
- Working in high-frequency ranges can reduce electromagnetic interference problems.
- Working with limited switching frequency control can bring high efficiency.

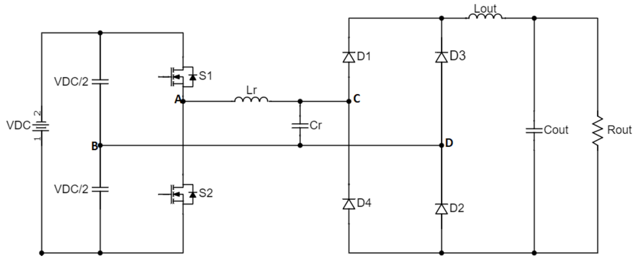


Fig. 2: Parallel Resonant DC/DC Converter Circuit

B. Converter Analysis

A square wave voltage with a magnitude of V_{DC} between $-V_{DC}/2$ and $V_{DC}/2$ is generated at the frequency determined by the switching operation and applied to the L_r-C_r network. Assuming sinusoidal voltage across capacitor C_r, the analysis of the parallel DC-DC converter can be undertaken, with consideration given to the only fundamental frequencies of the square wave voltage input and square wave current [5]. This assumption allows the converter to be modeled as a simple voltage source with a series resistor and inductor, which simplifies the analysis and design of the converter. Hence, AC analysis can be used to calculate the voltages of the equivalent circuit shown in Figure 3. The L_r-C_r network is designed to filter out all harmonic voltage components except for the fundamental component that exists in voltage VAB. The AC resistance, R_{ac}, is included in the AC equivalent circuit to represent the non-linear characteristics of the rectifier. The reactances of L_r and C_r are indicated by XL_r and XC_r respectively. To put it simply, the L_r, C_r network is a filter that only allows the fundamental voltage component to pass through, while the AC resistance and reactances of L_r and C_r are used to account for the non-linearities in the rectifier.

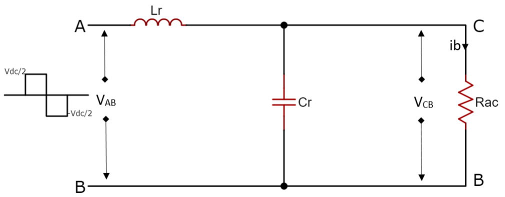


Fig. 3: Equivalent AC circuit

Equation (1) can be used for solving VCB voltage of the equivalent circuit in Figure 2.

$$\frac{V_{CB}}{V_{AB}} = \frac{1}{1 - \frac{XL_r}{XC_r} + j\frac{XL_r}{R_{ac}}} \tag{1}$$

VCB represents the amplitude of the fundamental frequency component of the input voltage waveform, also Ib refers to the amplitude fundamental frequency component of the square

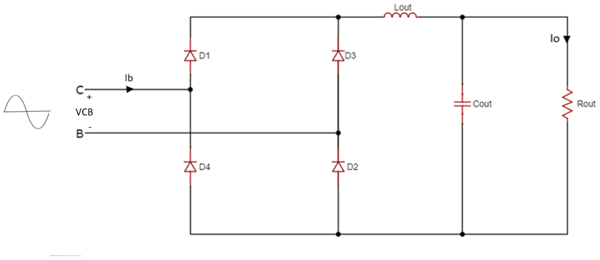


Fig. 4: R_{ac} Equivalent Circuit

wave current waveform. So, R_{ac} can be shown equivalent circuit is Figure 4 and calculated by Equation (2).

$$R_{ac} = \frac{V_{CB}(rms)}{I_b(rms)} = \frac{V_o \frac{\pi}{2}}{\frac{4I_o}{\pi}} = \frac{\pi^2}{8}\frac{V_o}{I_o} = \frac{\pi^2}{8} R_{out} \tag{2}$$

where Vo is the average value of the full-wave rectified voltage waveform at the output of the bridge as defined in Equation (3).

$$V_o = \frac{2V_{CB}(rms)}{\pi} \tag{3}$$

The resonant frequency, defined as f_o in Equation (4) is the point at which the circuit exhibits its highest response, and it is the most efficient operating point of the converter.

$$w_o = 2\pi f_o = \frac{1}{\sqrt{L_r C_r}} \tag{4}$$

The output voltage is a final expression as given in Equation (5).

$$V_o = \frac{4V_{DC}}{\pi^2 \sqrt{\left(1 - \frac{XL_r}{XC_r}\right)^2 + \left(\frac{XL_r}{R_{ac}}\right)^2}} \tag{5}$$

III. CALCULATIONS OF CIRCUIT PARAMETERS

The designed LNB power circuit is based on the principle of frequency control that varies with load changes and operates with a %50 duty cycle. In order to determine the operating frequencies of the circuit, the transfer function of the circuit has been calculated in terms of frequency using equations.

$$V_o^2 = \frac{16V_{DC}}{\pi^4 \left|\left(1 - \frac{XL_r}{XC_r}\right)^2 + \left(\frac{XL_r}{R_{ac}}\right)^2\right|} \tag{6}$$

$$XL_r = 2\pi f_s L_r \tag{7}$$

$$XC_r = \frac{1}{2\pi f_s C_r} \tag{8}$$

where f_s is the switching frequency as defined in Equation (9).

$$w_s = 2\pi f_s \tag{9}$$

Equations (7) and (8) are substituted and the resulting expression can be simplified as in Equation (10).

$$\frac{16V_{DC}^2}{V_o^2} = \pi^4 \left(1 - w_s^2 L_r C_r\right)^2 + \left(\frac{w_s L_r}{R_{ac}}\right)^2 \tag{10}$$

When the equation is rearranged into a two-variable equation format, the final form of the function is obtained as given in Equation (11).

$$w_s^4(L_r^2 C_r^2) + w_s^2\left(\frac{L_r^2}{R_{ac}^2} - 2L_r C_r\right) + 1 - \frac{16V_{DC}^2}{V_o^2 \pi^4} = 0 \tag{11}$$

Later, the discriminant method can be used to calculate the two root switching frequency values of the equation: one that is greater and one that is smaller than the resonant frequency.

$$\mathrm{f}_{sw1} = \sqrt{\frac{-\left(\frac{L_r}{R_{ac}}\right)^2 + 2L_r C_r + \sqrt{\left(\frac{L_r}{R_{ac}}\right)^4 - \frac{4L_r^3 C_r}{R_{ac}}^2 + \frac{64V_{DC}^2 L_r^2 C_r^2}{V_o^2 \pi^4}}}{8L_r^2 C_r^2 \pi^4}} \tag{12}$$

$$\mathrm{f}_{sw2} = \sqrt{\frac{-\left(\frac{L_r}{R_{ac}}\right)^2 + 2L_r C_r - \sqrt{\left(\frac{L_r}{R_{ac}}\right)^4 - \frac{4L_r^3 C_r}{R_{ac}}^2 + \frac{64V_{DC}^2 L_r^2 C_r^2}{V_o^2 \pi^4}}}{8L_r^2 C_r^2 \pi^4}} \tag{13}$$

The switching frequency in the designed circuit is f_{sw1} frequency selected which is to be higher than the resonant frequency to improve better stability of circuit behavior.

A. Proposed Circuit Calculations

V_{out} should be $13V$ for vertical polarization and $18V$ for horizontal polarization respectively. In this circuit, V_{DC} has been chosen as $12V$, the current limits have been defined to vary within the range of 1mA-500mA and the resonant frequency has been determined to be 300kHz. The calculations for V_{out} = $13V$ are as follows:

- V_{out} =13V, V_{DC}=12V, I_o=500mA;

$$R_{out} = \frac{V_o}{I_o} = \frac{13V}{500mA} = 26\Omega \tag{14}$$

R_{ac} can be calculated using Equation 2.

$$R_{ac} = \frac{\pi^2}{8} 26 = 32.07\Omega \tag{15}$$

- V_{out} =13V, V_{DC}=12V, I_o=1mA;

$$R_{out} = \frac{V_o}{I_o} = \frac{13V}{1mA} = 13k\Omega \tag{16}$$

$$R_{ac} = \frac{\pi^2}{8} 13k = 16.038k\Omega \tag{17}$$

When the values of R_{ac}, V_o, and V_{DC} are substituted into the switching frequency equation in Equation (12) for both maximum current and minimum current, the operating frequency range (Δf) can be decided.

$$\mathrm{f}_{sw,1mA} = \sqrt{\frac{-\left(\frac{L_r}{16038}\right)^2 + 2L_r C_r + \sqrt{\left(\frac{L_r}{16038}\right)^4 - \frac{4L_r^3 C_r}{16038}^2 + (0.559L_r^2 C_r^2)}}{8L_r^2 C_r^2 \pi^4}} \tag{18}$$

$$\mathrm{f}_{sw,500mA} = \sqrt{\frac{-\left(\frac{L_r}{32.07}\right)^2 + 2L_r C_r + \sqrt{\left(\frac{L_r}{32.07}\right)^4 - \frac{4L_r^3 C_r}{32.07}^2 + (0.559L_r^2 C_r^2)}}{8L_r^2 C_r^2 \pi^4}} \tag{19}$$

The calculations for V_{out} = 18V are as follows:

- V_{out} =18V, V_{DC}=12V, I_o=500mA;

$$R_{out} = \frac{V_o}{I_o} = \frac{18V}{500mA} = 36\Omega \tag{20}$$

R_{ac} can be calculated using Equation 2.

$$R_{ac} = \frac{\pi^2}{8} 36 = 44.41\Omega \tag{21}$$

- V_{out} =18V, V_{DC}=12V, I_o=1mA;

$$R_{out} = \frac{V_o}{I_o} = \frac{18V}{1mA} = 18k\Omega \tag{22}$$

$$R_{ac} = \frac{\pi^2}{8} 18k = 22.206k\Omega \tag{23}$$

$$\mathrm{f}_{sw,1mA} = \sqrt{\frac{-\left(\frac{L_r}{22206}\right)^2 + 2L_rC_r + \sqrt{\left(\frac{L_r}{22206}\right)^4 - \frac{4L_r^3C_r}{22206}^2 + (0.292L_r^2C_r^2)}}{8L_r^2C_r^2\pi^4}} \tag{24}$$

$$\mathrm{f}_{sw,500mA} = \sqrt{\frac{-\left(\frac{L_r}{44.42}\right)^2 + 2L_rC_r + \sqrt{\left(\frac{L_r}{44.42}\right)^4 - \frac{4L_r^3C_r}{44.41}^2 + (0.292L_r^2C_r^2)}}{8L_r^2C_r^2\pi^4}} \tag{25}$$

B. Selection L_r and C_r values

The L_r and C_r components are obtained from Eqn 5.

$$L_rC_r = \left(\frac{1}{2\pi f_o}\right)^2 \tag{26}$$

After selecting resonant frequency f_o as 300kHz, is expressed as

$$L_rC_r = 28.14 \cdot 10^{-14} \tag{27}$$

When L_r value is written as an equation in terms of C_r, the Δf $(f_{sw,1mA} - f_{sw,500mA})$ graph can be plotted as a function of the C_r values for output voltages of 13V and 18V.

$$C_r = \frac{28.14 \cdot 10^{-14}}{L_r} \tag{28}$$

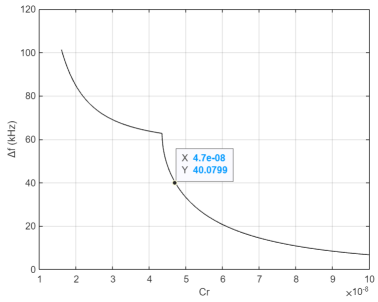


Fig. 5: Operating frequency differences (Δf) for V_{out}=13V at f_o=300kHz

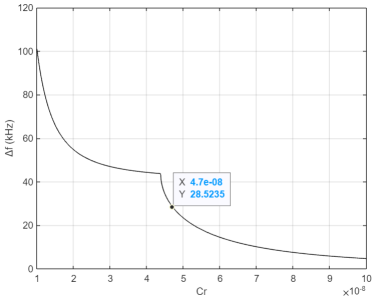


Fig. 6: Operating frequency differences (Δf) for V_{out}=18V at f_o=300kHz

As seen in Figure 5 and Figure 6, the slope of the curves changes after a certain point, because there is an imaginary part at the f_{500mA} switching frequency. When considering only the real parts and taking the capacitance value as a readily obtainable parameter, a capacitance value of 47nF has been selected as the maximum value for the Δf. So, L_r can be calculated by Equation (28).

$$L_r = \frac{28.14 \cdot 10^{-14}}{47 \cdot 10^{-9}} = 6uH \tag{29}$$

When the equations are substituted in order, the switching frequencies are found in Table I.

TABLE I: Maximum and minimum switching frequencies

Horizontal/Vertical	**Minimum** f_{sw} $f_{(sw,500mA)}$ ***(kHz)***	**Maximum** f_{sw} $f_{(sw,1mA)}$ ***(kHz)***
13V	311.18	351.29
18V	309.18	337.70

Approximate operating frequency ranges are

$$\Delta f = \begin{cases} 28kHz, \mathrm{V}_{out} = 18V \\ 40kHz, \mathrm{V}_{out} = 13V \end{cases} \tag{30}$$

Therefore, the circuit's operating frequency range has been designed between 309 kHz and 351 kHz.

C. Selection of Lo and Co

To ensure that the average value of current and voltage ripple does not exceed 10%, and to prevent any interference from the switching frequency, a $10uH$ inductor and a $100uF$ capacitor have been selected, with a cut-off frequency lower than 300 kHz.

IV. SIMULATION RESULTS

The proposed LNB power circuit has been simulated using Matlab Simulink, which is a parallel resonant converter circuit designed with PI feedback, as shown in Figure 7. The required switching frequencies for minimum and maximum currents for $18V$ output voltage are shown in Figures 8 and Figure 9. Similarly, the required frequencies for minimum and maximum currents for $13V$ output voltage are shown in Figure 10 and Figure 11. In simulation studies, diodes and MOSFETs are considered ideal. The circuit is designed to have a maximum output current of $500mA$, and the current is limited by using a PI controller to maintain the current within the calculated frequency range without exceeding 500mA. In the proposed circuit, an overdamped PI control has been designed to provide the output voltage stabilized to the desired value and simultaneously minimize undesired overshoots. As shown in Figure 12, the circuit's maximum output current within the specified frequency range (309 kHz-351 kHz) has been simulated when the output resistance is nearly zero, as in the case of a short circuit. In Figure 13, it is noted that the maximum output current has been measured as 13.2A when the output voltage of an LNB IC has been short-circuited. However, it has been shown by simulation that current peaks can not occur in short-circuit conditions in the operating frequency range, thanks to the use of the parallel resonant converter circuit.

A PI control circuit was designed to create a control loop that predicts output changes by adjusting to the frequency range. In the design, the output current was set to 1mA, and a MOSFET operating with a 500ms period was used. A parallel resistor was connected to the MOSFET's output. With these settings, the output current was increased from 1mA to 500mA as demonstrated in Figure 14(a), and changes in the circuit's output were observed. The suitability of the Proportional (P) and Integral (I) parameters of the PI control circuit was evaluated through this simulation process. As seen more clearly in Figure 14(b), the proposed circuit has been reached steady state point roughly 0.05 second.

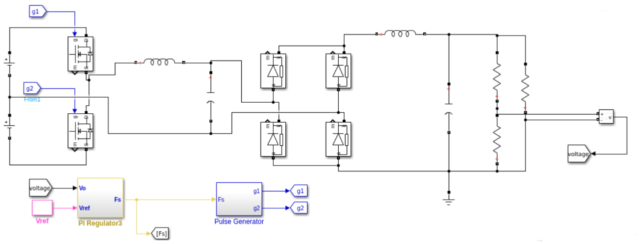


Fig. 7: Parallel Resonant DC/DC Converter Simulation Circuit with PI controller feedback

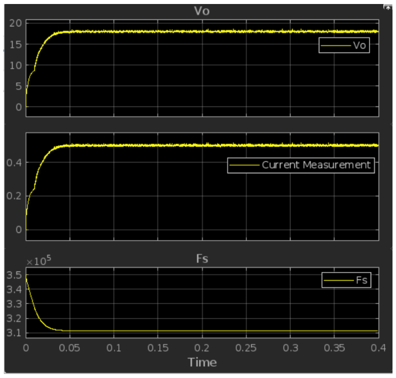


Fig. 8: Simulation results for $V_o = 18V$ and $I_o = 500mA$

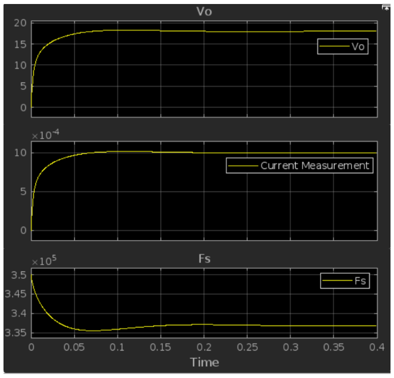


Fig. 9: Simulation results for $V_o = 18V$ and $I_o = 1mA$

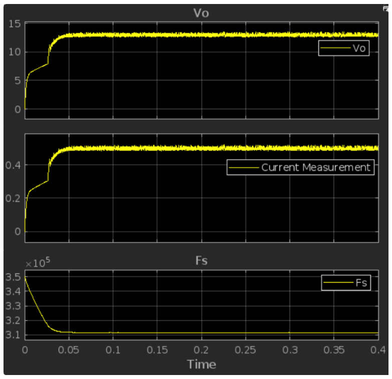


Fig. 10: Simulation results for $V_o = 13V$ and $I_o = 500mA$

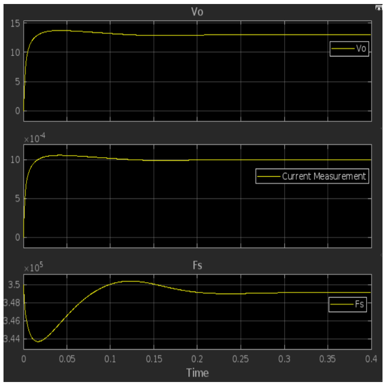


Fig. 11: Simulation results for $V_o = 13V$ and $I_o = 1mA$

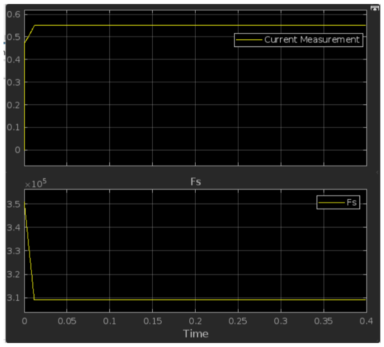
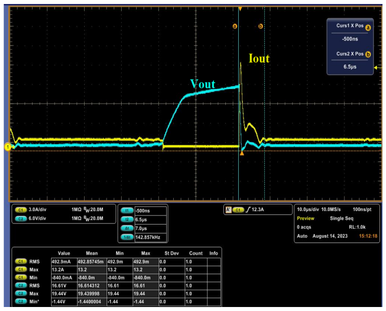


Fig. 12: Simulation results for Short Circuit $V_o = 0V$ and $R_{out} = 0.01R$



C1 3.0A/div 1MΩ BW:20.0M
C2 6.0V/div 1MΩ BW:20.0M

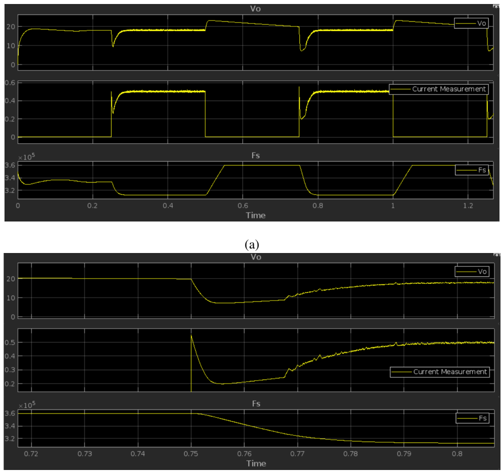
t1 -500ns
t2 6.5µs
Δt 7.0µs
1/Δt 142.857kHz

A' C1 12.3A

10.0µs/div 10.0MS/s 100ns/pt
Preview Single Seq
0 acqs RL:1.0k
Auto August 14, 2023 15:12:18

		Value	Mean	Min	Max	St Dev	Count	Info
C1	RMS	492.9mA	492.85745m	492.9m	492.9m	0.0	1.0	
C1	Max	13.2A	13.2	13.2	13.2	0.0	1.0	
C1	Min	-840.0mA	-840.0m	-840.0m	-840.0m	0.0	1.0	
C2	RMS	16.61V	16.614312	16.61	16.61	0.0	1.0	
C2	Max	19.44V	19.439998	19.44	19.44	0.0	1.0	
C2	Min*	-1.44V	-1.4400004	-1.44	-1.44	0.0	1.0	

Fig. 13: LNB Power IC peak current measurement during Short Circuit Test Condition



(a)

(b)

Fig. 14: Simulating the steady-state performance of the designed circuit

V. CONCLUSION

This study focuses on the new design of a LNB Power circuit using a parallel resonant DC/DC converter. The principle of frequency control operation was used to provide up to $500mA$ current according to load changes. To design the circuit, the necessary currents and frequencies were calculated, taking into account the $13V$ (Horizontal)/$18V$ (Vertical) load variations required for the LNB Power circuit. The circuit uses a parallel resonant converter DC/DC converter has a constant current source, which limits the current up to $500mA$ with frequency control. This feature helps to avoid installation problems with satellite cables, which is a common issue with voltage-controlled boost converter DC/DC converters used in LNB Power circuits. Furthermore, the converter was selected for its ability to prevent short-circuit problems during wiring. This study presents a new approach to the design of the LNB Power circuit using a parallel resonant converter DC/DC converter with frequency control. This design can help improve the performance and reliability of satellite receiving systems.

REFERENCES

[1] Y. Konishi and Y. Fukuoka, ”Satellite receiver technologies,” in IEEE Transactions on Broadcasting, vol. 34, no. 4, pp. 449-456, Dec. 1988, doi: 10.1109/11.16488.

[2] P. Philippe et al., ”A low power 9.75/10.6GHz down-converter IC in SiGe:C BiCMOS for Ku-band satellite LNBs,” 2011 IEEE Bipolar/BiCMOS Circuits and Technology Meeting, Atlanta, GA, USA, 2011, pp. 211-214, doi: 10.1109/BCTM.2011.6082784.

[3] K. Miyashita, ”A plastic packaged Ku-band LNB with very high susceptibility to supply PLL in 0.18um CMOS,” 2010 Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF), New Orleans, LA, USA, 2010, pp. 188-191, doi: 10.1109/SMIC.2010.5422974.

[4] Richtek Technology Corp.,”RT5047A-00 Voltage Regulator Datasheet,March 2015.

[5] Hart,D.,(2010), Power Electronics,(I),McGraw-Hill Education,New York, pp. 414-417.