

Design of High Gain Low Noise Amplifier at Base Station Receiver VOR Equipment for Ground Check Monitoring as Learning Media in Civil Aviation Academy

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Abstract – This paper present the design of an high-gain low-noise amplifier (LNA) in the application of base station receiver very high frequency omnidirectional range (VOR) for ground check monitoring. VOR is within the 108–118 MHz frequency band. LNA serves as an essential part of radio receiver systems. It amplifies a very-weak signal captured by an antenna by adding a little noise and minimizing signal distortions. LNA comes with some specifications to which attention should be paid, namely, stability, noise figure, gain, return loss, and bandwidth. The design in this research employs lumped components. The LC tank resonator designed resonates at a center frequency of 113.0 MHz with the 2SC3583 transistor, with small-signal amplifier characteristic highly suitable for LNA application over the VHF band. DC bias use the collector feedback biasing configuration. It is hoped that the amplifier works in class A. The results of the simulations at the center frequency of 113.0 Mhz. This design has desirable parameters satisfying the design specifications and will be applicable to VOR base station receiver equipment for ground check monitoring at the laboratory of Civil Aviation Academy.

Keywords – Low Noise Amplifier, very high frequency omnidirectional range, Learning Media

I. INTRODUCTION

Aviation navigational facility service is indispensable in air traffic service (ATS) with the use of radio navigation aids (RNAs). One of such radio navigation aids is very high frequency omnidirectional range (VOR) which works over the VHF band within an allocated frequency range of 108–118 MHz, mounted in a given location in or out of airport environments, to serve the function of providing information of azimuth or bearing direction (radial) of aircraft to the VOR station. VOR topologies are split into two types: conventional VOR (CVOR) and Doppler VOR (DVOR). The two types work under separate principles but produce identical azimuth information by comparing the phases of two guidance signals: 30-Hz reference signal and 30-Hz variable signal. The increasingly busy air traffic must be supported by reliable, accurate, continuously-available navigational

services. To support and ensure flight safety, it is required to inspect the performance of the equipment through both flight inspection and ground inspection. Flight inspection is carried out on the above equipment periodically every 12 months, but the cost incurred for doing so is fairly high. Meanwhile, ground inspection involves monitoring the transmission of Radio Navigation Aids, especially VOR equipment, in the proximity of the equipment installation site, be it in the near field or in the far field. Inspection can be aided by a navigation analyzer or a specifically designed base station receiver VOR application. Not all airport managers are equipped with a navigation analyzer for many reasons, including high price of the instrument. The ground inspection data collection and reporting by the instrument are all conducted manually. On the opposite site of the spectrum, base station receiver VOR can be designed as a lower-cost

tool that can be used in a remote monitoring system in real time on a continual basis if installed as a monitoring sensor. The parametric data from VOR transmission can subsequently be processed for ground inspection reporting. Given the issue above, it is thus deemed necessary to design an uncomplicated, cost-effective, easy-to-use base station receiver VOR application to monitor the DVOR parameter continuously. This design is to be applied at the laboratory of flight academies, one of which is Politeknik Penerbangan Indonesia Curug, to facilitate the teaching and learning process and to enhance competency of the students [1], [2]. Receipt of the audio signal carried through an RF carrier can simply be achieved by means of base station receiver VOR. In principle, base station receiver VOR resembles conventional receivers. It is to use RTL-SDR radio receiver. However, the making of the VOR receiver menu application is only to be conducted in future study.

II. LITERATURE REVIEW AND FRAMEWORK

2.1 DVOR Transmitter

DVOR is an aviation navigation facility that works within the frequency range of 108–118 MHz and is mounted in a given location in or out of airport environments to serve the function of providing information of azimuth or bearing direction (radial) of aircraft to the VOR station. This transmitter is comprised of an RF carrier transmitter which transmits through one middle antenna and an RF sideband transmitter (USB and LSB) which channels through 48 sideband antennas at the counterpoise edge [5], [8]. This equipment draws on the Doppler effect in its transmission system, especially on the RF sideband signal, for position accuracy and signal stability. Doppler effect is rendered by setting the rotating sideband antenna transmission (alternating between one antenna and the next consecutively). The antenna transmission is rotated counterclockwise electronically to bring about a change in the frequency on the airborne sub-carrier which will form a sine wave if received by a receiver at a given point reachable by the DVOR transmission [5]. DVOR transmits signals which consist of two components: 30-Hz reference signal and 30-Hz variable signal. By comparing the phases of the two 30-Hz signal components, the azimuthal position of the aircraft in relation to the DVOR location can be identified. The 30-Hz reference signal is transmitted by AM technique through a carrier antenna omnidirectionally with an instantaneous phase around the same DVOR at every azimuth from 0–360° [7]. The 30-Hz variable signal, on the other hand, is obtained through FM technique at the sub-carrier frequency, while the sub-carrier frequency per se is a difference between the RF

carrier frequency and the RF sideband frequency occurring in the airspace (space modulation) resulted by the rotated sideband antenna transmission, causing the sideband frequency to fluctuate [6].

2.2 VOR Receiver

The VOR receiver on an aircraft is used to receive the signal transmitted from the VOR ground station, and the signal carried by the RF carrier is detected to generate a 30-Hz AM reference signal and a 30-Hz FM variable signal, both of which are to be analyzed for the phases [8]. The 30-Hz reference signal is received from the detected RF carrier signal whose phase remains in azimuth anywhere between 0° and 360°, while the 30-Hz variable signal is received from the detected 960-Hz sub-carrier signal, whose phase in which the signal is received by the receiver, due to the Doppler effect, would vary with the aircraft position [13]. The phases of the two signals are then compared, and the difference in between is used to indicate the azimuth or bearing position of the aircraft (radial) in relation to the DVOR transmitter. The following is the block diagram of the aircraft VOR receiver.

2.3 Flight Inspection

The DVOR parameters check through Flight Inspection is divided into five types [10]:

Site evaluation, a type of flight inspection for determining the feasibility of a proposed location for permanent facility installment. Inspection of this sort may include checking like commissioning inspection and other additional inspections when needed.

Commissioning, a type of comprehensive flight inspection over newly installed flight navigation facilities to gain detailed information like that of the system performance and to ensure that the system is able to meet the operating requirements.

Periodic inspection, a type of flight inspection performed on a periodic/scheduled basis to determine if the system has met the operating standards and requirements. Periodic inspection of DVOR equipment is conducted every 12 months.

Special inspection, a type of flight inspection performed outside the flight inspection schedule. This is used to evaluate the performance characteristics of the system, subsystem, or facility [4]. The facility maintenance engineer is responsible for coordinating the flight calibration inspectors who perform the inspection based on the requirements and type of maintenance used.

Surveillance, a continuous observation of the components of the system, procedure, or service. The inspection conducted includes spot check over the normal flight operation

2.4 Ground Inspection

Ground inspection is conducted at least once every month around the site of the DVOR transmitter (near field or far field), including several observation points. The parameters checking with the instrument navigation analyzer or portable ILS receiver (PIR) is as can be seen in the figure 1 below



Fig 1. VOR parameters reading with Nav Analyzer

2.5 Radio Base Station VOR Receiver

Receiver devices are developing rapidly, with not only AM receiver and superheterodyne receiver were introduced, but also the SDR (software-defined radio) system. The last in the list is programmable, but in principle it is the same as the first two. The components of a receiver include an RF amplifier, an oscillator, a mixer, an IF amplifier, a detector, and an audio amplifier. To increase the sensitivity of a receiver, an LNA (low-noise amplifier) circuit is needed [12].

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2.6 LNA

Low-noise amplifier (LNA) is the front-end of a receiver or RF field detector system [9]. The function is to amplify signals with minimal noise and acceptable gain to the output part of the receiver and to provide stability without oscillation over the frequency desired.

III. RESULT AND DATA ANALISYS

3.1 High Gain LNA

In the design, high-gain LNA is used as a front amplifier for the VOR radio receiver to obtain greater signal sensitivity, allowing very-weak signals to be received by the receiver. Hence, high-gain LNA is of considerable importance.

3.2 LNA Specifications

The first step to LNA designing is to determine the characteristics and specifications of the LNA to be designed.

Detailed description is provided in Table 1.

TABLE 1 LNA Specifications

Specification	HIGH-GAIN LNA
Frequency range	108–118 MHz
Center frequency	113.0 MHz
Bandwidth	10 MHz $\pm$ 2 MHz
Stability	K > 1
Noise figure	< 2 dB
Gain (S_{21})	> 20 dB
Inp return loss (S_{11})	< 10 dB

3.3 Transistor Selection

To design an LNA, the first step is to select a transistor according to the required specifications. The aspects to which attention should be paid are low power consumption, noise figure, and gain [8]. Transistor selection here is aided by the ADS software which comes with a library of various transistor models applicable to the LNA design. The transistor selected is the 2SC3583 transistor as it functions as a small amplifier which is suitable to be applied as a low-noise amplifier [10]. Besides, the 2SC3583 transistor works at the frequency highly suitable for VHF and UHF applications as per the sheet data provided by the manufacturer, and it has sufficient gain and low noise. Transistor of this type is an NPN-type bipolar junction transistor (BJT). NPN type is used because the higher-velocity electron movement is capable of rendering a higher current. A transistor consists of a base terminal, an emitter, and a collector.

3.4 DC Bias Transistor

To determine the working area of a dual-band LNA amplifier, transistor biasing is needed. In this work, the transistor type proposed for selection is the 2SC3583 transistor under the collector-feedback biasing configuration. Base current I_B is derived from collector voltage V_{CE} through positive bias resistor R_{B1} , whereas R_{B2} serves as a current divider allowed to flow to base transistor I_B and the current heading to the ground [9]. Transistor biasing is calculated using the equations given below.

DC transistor biasing target: $V_{CE} = 2.0$ V, $I_C = 10$ mA, DC supply $V_{CC} = 12$ V. Based on the datasheet, $V_{BE} = 0.8$ V and $\beta = 110$.

Determining the R_{B1} and R_{B2} values: Based on the DC gain transistor (β).

3.5 Z_{IN} and S-Parameter Values Of Bias Transistor

To find the input impedance and reflection coefficient values, Z_{IN} and S-parameter values are calculated. This transistor has a substituting non-linear model circuit as shown in Figure 2 and Table 2

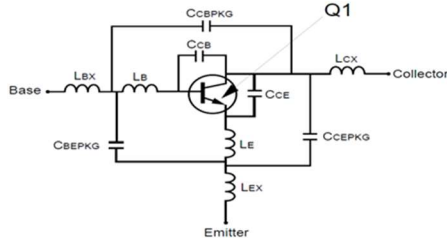


Fig 2. Substituting Non-Linear Model Circuit for 2SC3583 Transistor

TABLE 2 List of Small-Signal Component Values in Farad and Henry Units

Parameter	2SC3583
C_{CB}	0.07e-12
C_{CE}	0.01e-12
L_B	0.9e-9
L_E	1.2e-9
C_{CBPKG}	0.2e-12
C_{CEPKG}	0.2e-12
C_{BEPKG}	0.01e-12
L_{BX}	0.3e-9
L_{CX}	0.6e-9
L_{EX}	0.3e-9

Meanwhile, the bias circuit proposed uses the single-transistor topology by matching networks technique using serial inductive emitter degeneration (L_E), parallel capacitor base emitter (C_{BE}), and serial capacitor base (C_{IN}) as shown in Figure 3

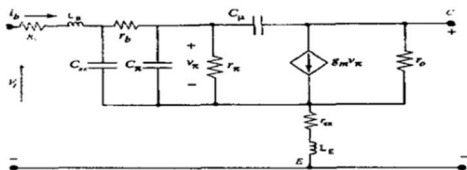


Fig 3. Equivalent Small-Signal Bias Transistor Circuit

By the ADS simulation, the value can be measured more accurately. The Z_{IN} and S-parameter measurement for both working frequencies is as presented in Table 3

TABLE 3 Results of the Z_{IN} and S-Parameter Measurement Simulation

freq	Zin1	S(1,1)	S(1,2)	S(2,1)	S(2,2)
108.0 MHz	46.807 - j213.649	0.911 / -25.232	0.010 / 142.858	4.866 / -101.376	0.698 / -39.596
109.0 MHz	47.182 - j211.609	0.909 / -25.430	0.010 / 142.361	4.920 / -102.351	0.692 / -39.843
110.0 MHz	47.552 - j209.615	0.907 / -25.626	0.010 / 141.866	4.973 / -103.323	0.685 / -40.079
111.0 MHz	47.918 - j207.666	0.905 / -25.819	0.010 / 141.372	5.026 / -104.290	0.678 / -40.306
112.0 MHz	48.279 - j205.764	0.903 / -26.019	0.010 / 140.880	5.077 / -105.263	0.671 / -40.530
113.0 MHz	48.635 - j203.898	0.900 / -26.199	0.010 / 140.390	5.128 / -106.211	0.664 / -40.727
114.0 MHz	48.987 - j202.075	0.898 / -26.385	0.011 / 139.903	5.177 / -107.165	0.656 / -40.922
115.0 MHz	49.333 - j200.293	0.896 / -26.569	0.011 / 139.418	5.226 / -108.114	0.651 / -41.106
116.0 MHz	49.674 - j198.550	0.894 / -26.751	0.011 / 138.936	5.274 / -109.058	0.644 / -41.278
117.0 MHz	50.010 - j196.845	0.892 / -26.931	0.011 / 138.456	5.321 / -109.997	0.637 / -41.440
118.0 MHz	50.340 - j195.176	0.889 / -27.108	0.011 / 137.979	5.367 / -110.931	0.630 / -41.589

The table above shows that the center frequency of each LNA working frequency must be matched with the R_s source input = 50Ω to derive a small return loss value (S_{11}) in accordance with the LNA specification (≤ 10 dB).

2.7 Stability Check

In the design of a microwave amplifier circuit, one of the critical factors to be considered is the stability factor. Stability is highly determinant of the amplifier's condition, that is to say, whether it is under a stable condition or whether it is oscillating.

Based on the results of the K factor calculation, the stability of K factor at the frequency of 113.0 MHz is higher than 1 (1.140). This suggests that the transistor is under a stable condition. A graphical representation of the K factor's stability in relation to the frequency is provided in Figure 4

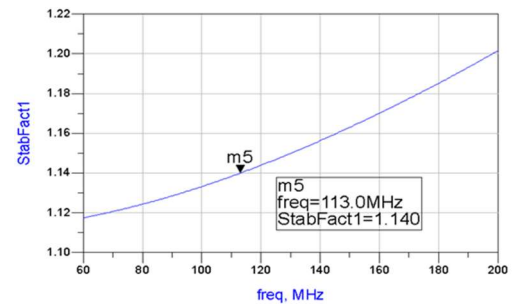


Fig 4. Results of the Bias Transistor Stability Simulation

Meanwhile, the gain (S_{21}) simulation generates a result greater than 20 dB at the working frequency, meaning that the designed LNA specification as shown in Table 4.1 has been met. The graphical representation of the S_{21} simulation in the bias transistor is provided in Figure 5.

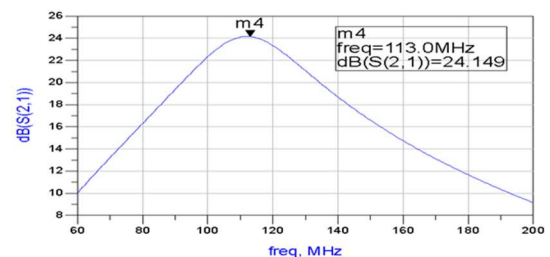


Fig 5. Results of Gain (S_{21}) Simulation in the Bias Transistor

3.7 Input Impedance Matching

This design involves input impedance matching on the LNA. The dual-band LNA circuit with input matching can be seen in Figure 6.

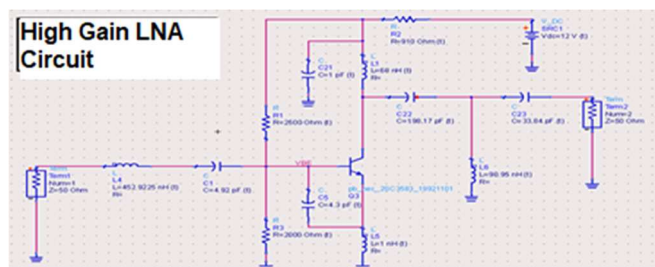


Fig 6. Dual-Band LNA Circuit with Input Matching

According to the flow chart developed, the circuit is to be simulated with ADS, and the results of the stability, noise figure, input return loss (S_{11}), gain (S_{21}), and VSWR simulations will be discussed in the Circuit Simulation Results section.

3.8 Circuit Simulation Results

This section will discuss the results of the LNA simulations at the center frequency of 113.0 MHz. The simulations are conducted with the Advanced Design System (ADS) software.

Stability Simulation Result: The result of the stability simulation is presented in Figure 4, while the K value obtained by factoring in S-parameter value into calculation is presented in Table 4. This value is derived from the S-parameter simulation with the ADS software.

TABLE 4 S-Parameter Value from Simulation

Center	(S_{11})	(S_{12})	(S_{21})	(S_{22})
Freque	Mag/angl	Mag/angl	Mag/angl	Mag/angl
ncy	e (°)	e (°)	e (°)	e (°)
113.0	0.058/30.	0.034/47.	16.062/16	0.247/55.
MHz	380	708	1.22	633

The calculation is as explained in the Theoretical Review and Framework section. From the stability measurement, the K value at the frequency 113.0 MHz was 1.140. The K value > 1 shows fulfilment of the LNA requirement (unconditionally stable).

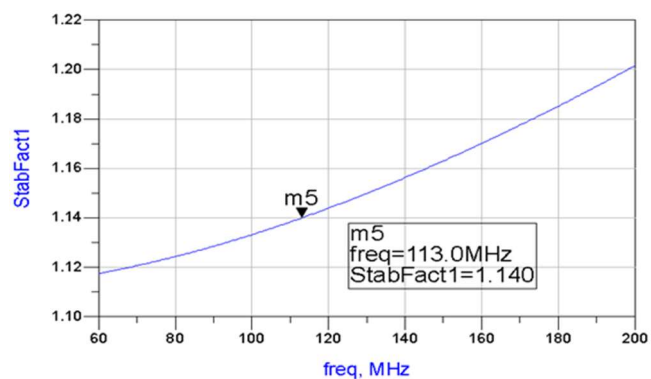


Fig 7. LNA Stability Factor Simulation

Results of S_{11} and S_{21} Simulations: The results of the S_{11} and S_{21} simulations as the input return loss and gain of the LNA system are as the S-parameters in the complete circuit figure above. As shown in Figure 3.9, The S_{11} and S_{21} values measured at the frequency 113.0 MHz are -85.152 dB and 24.149 dB, respectively, and the bandwidth reached at the $S_{11} < -10$ dB threshold is around 10 MHz. The input return loss value meets the LNA design requirement. Similarly, the S_{21} simulation result also meets the design specification, that is, it is able to produce a value greater than 20.0 dB.

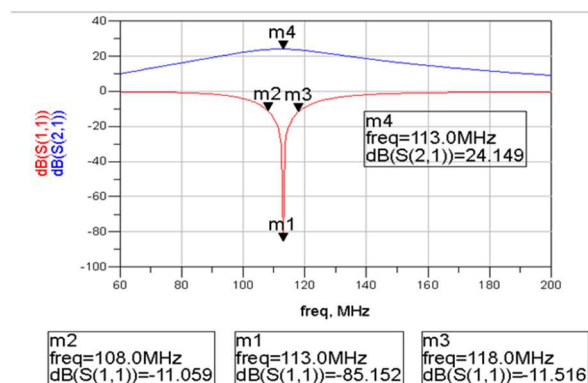


Fig 8. High-Gain LNA S_{11} and S_{21} Simulations

VSWR Simulation Result: The result of the simulation for the voltage wave standing ratio (VSWR) is as shown in Figure 3.10. The result achieved is smaller than 2 for the working frequency of each band. The measurement at the center frequency of 113.0 MHz is 1.000.

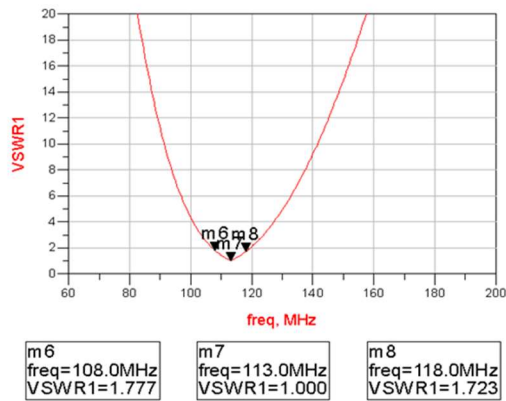


Fig 9. LNA VSWR Simulation

Results of Noise Figure (NF) Simulation: Another measurement equally crucial is the noise figure, as it is highly determinant of the signal quality (SNR) produced at a receiver output. Hence, it is important that the NF value is minimal. In this simulation, the NF value resulted at the center frequency of 113.0 MHz is 1.263 dB. This, too, has met the designed LNA requirement with a value of <2.

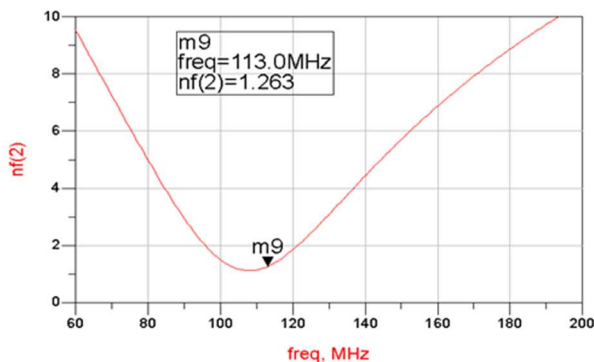


Fig 10. LNA Noise Figure Simulation

IV. CONCLUSION

Based on the results of the design and simulation performance analysis of the LNA at a center frequency for monitoring ground check by RF VOR receiver application, the simulation results show good performance. The appropriately selected transistor in accordance with the transistor function as an LNA for VHF applications in VOR equipment has fairly high gain and small NF. The transistor is fit for use in LNA design for radio VOR receiver application.

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