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THESIS
IN
OPTICAL FIBER SYSTEMS M

EXPERIMENTAL STUDY OF A SYSTEM FOR COMPENSATING THE TEMPERATURE – INDUCED GAIN FLUCTUATIONS OF THE RADIO-OVER-FIBER LINKS USED IN THE SQUARE KILOMETRE ARRAY

CANDIDATE:
MOSTAFA NASIRI

SUPERVISOR:
Prof. JACOPO NANNI

Co-Supervisors:
Prof. Giovanni Tartarini
Eng. Federico Perini
Eng. Federica Caputo

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Abstract

The Square Kilometer Array-low (SKA-low) system requirements for high sensitivity and dynamic range are met in large part by the signal reception chain. The choice of architecture and receiver system design for SKA-low is influenced by the trade-off between gain, linearity, and low power consumption as well as cost, high reliability, robustness under extreme environments, and finally, the distance between the antennas and the acquisition systems. RF-over-fiber systems have been chosen as the technology for the SKA-low RF signal conveyance. Together with explanations of the creation of the receiver prototypes, the selection's justifications are presented. At the chosen SKA-low site in Western Australia, the prototypes were set up and put on demonstrator arrays. The thermal characterization of the receiver system has received particular focus, especially when both the optical medium and the transmitting component are subject to fluctuations in the ambient outside temperature. For this reason, particular emphasis has been placed on the analysis of optical receivers, both those currently used in AAVS2 and those that will be used for in the future for AAVS3. Finally, several simulations were conducted using software developed to describe the behavior of signals received following propagation through RF-over-fiber systems under certain environmental conditions.

CHAPTER 1

1.1) Introduction to SKA-Low

The introduction establishes the context by emphasizing the extensive application of Analog Radio Frequency-over-Fiber (RFoF) technology in a variety of industries, including cable television, mobile telephones, and radio astronomy instrumentation. The historical backdrop emphasizes its efficacy in transporting TV signals over great distances, taking advantage of optical fiber properties such as low attenuation, high bandwidth, and immunity to electromagnetic interference.

The revolutionary influence of RFoF on mobile telecommunications is stressed, notably in providing coverage in radio-darkened locations, particularly in underdeveloped countries. The research situates itself within the framework of the costly constraints connected with the Square Kilometer Array's low-frequency band coverage version (SKA-low) within this technological landscape.

Figure 1 : SKA-Mid Antennas[Left Side] – SKA-Low Antennas[Right Side]

The SKA-low, which operates in the 50 to 350 MHz spectrum, requires the installation of 131,072 antennas throughout Western Australia[1]. Because of the harsh environmental conditions and limited pre-existing infrastructure, a unique architecture with a central processing facility (CPF) and remote processing facilities (RPFs) is required, all of which are linked by an innovative digital transmission system. The introduction emphasizes the importance of ensuring radioastronomical signal fidelity over distances ranging from 500 meters to a few kilometers. Given its ability to fulfill environmental limits, the decision to employ optical fiber as the transmission route is warranted. RFoF-based linkages connect radioastronomical signals from 512 array stations to the CPF or correspondent RPF in the SKA-low configuration. The final component of the paper discusses the sophisticated design of the RFoF receiver for SKA-low, which was produced through a series of design and refinement processes based on demonstrator stations. Highlighted are two such demonstrators, AAVS and EDA, each with 256 double polarization antennas.

1.2) RFOF Technology in Radio Astronomy and in SKA-Low

The traditional method of signal transport from the antenna to the reception and processing system in radio astronomy involves the use of coaxial cables. While coaxial cables can operate at up to 60 GHz, their limitations, such as RF loss and frequency-dependent loss, impose limits on their maximum length, particularly in systems with multioctave bandwidths. As a result, optical fiber appears as a viable alternative in situations when distance and RF bandwidth are crucial.

Radio Frequency-over-Fiber (RFoF) technology has long been used in radio astronomy. As RFoF technology advances, it will eventually replace coaxial links in existing radio telescopes like the Northern Cross and Medicina VLBI dishes. However, because to concerns about location, construction, cost, reliability, and maintainability, its use in huge low-frequency arrays has been a source of debate in the radio astronomy community for nearly two decades.

Table 1: Different radio astronomical facilities formed by a high number of antennas

Name	Location	Bandwidth (MHz)	DL length	DLtechnology
CHIME	CANADA	400 to 800	50 mRF	over Coax
HIRAX	SOUTH AFRICA	400 to 800	UP to 1 km	RFoF
GMRT	INDIA	50 to 1500	UP to 20 km	RF/IF ove fiber
HERA	SOUTH AFRICA	100 to 200	150 to 500 m	RF over Coax/RfoF
LOFAR	NETHERLANDS	10 to 250	200 m	RF over Coax
MWA	AUSTRALIA	80 to 300	5 km	RF over Coax/RFoF
OVRO LWA	USA	27 to 85	Up to few km	RF over Coax/RfoF
SKA-Low	AUSTRALIA	50 to 350	6 km	RFoF

Table 1 depicts the many options currently used for antenna downlinks in large radio astronomy facilities operating at frequencies less than 2 GHz, emphasizing the lack of a general solution. Figure 1.2.1compares extensively distributed Remote Processing Facilities (RPFs) as seen in the low-frequency array radiotelescope (LOFAR) with a layout featuring a single Central Processing Facility (CPF) and a limited number of RPFs in the case of the SKA-low radiotelescope.

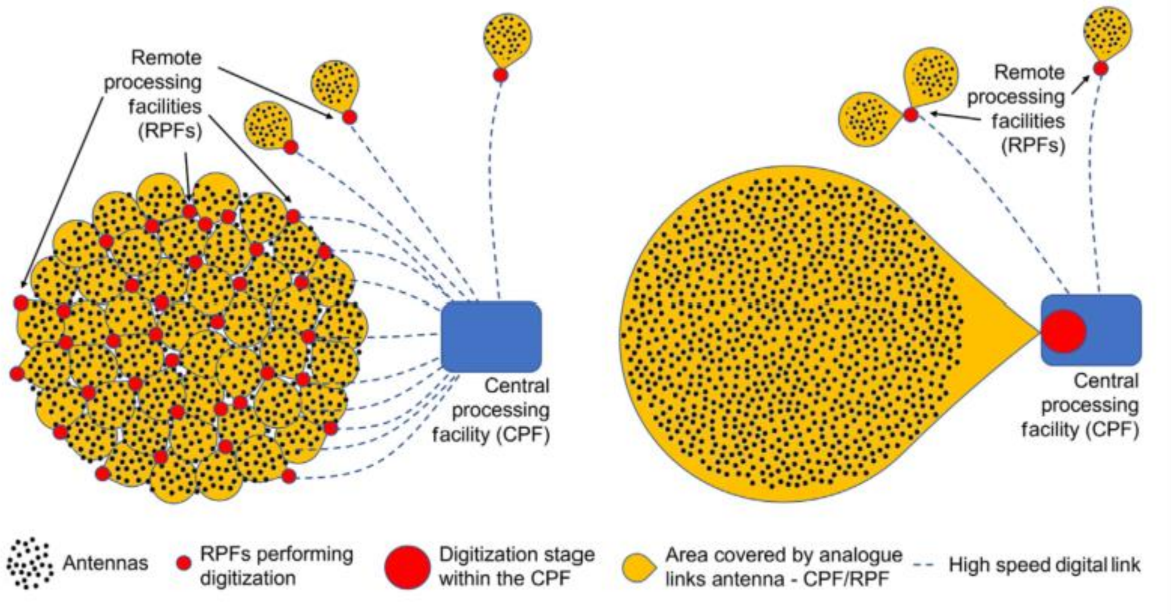

Figure 1.2.1 : Examples of different array configurations. (a) LOFAR: all antennas are connected to extensively distributed RPFs. (b) SKA-low: a subset of antennas is connected to a relatively low number of RPFs while their major part is directly connected to the CPF.

The limits of coaxial cables become clear when considering the SKA-low array arrangement, where relatively few RPFs collect signals from a subset of antennas and a single CPF directly receives signals from the bulk of antennas at distances of a few kilometers. It demonstrates how, due to environmental constraints in Murchison, the use of optical fiber in the SKA-low architecture is critical. The decision to deploy Radio Frequency-over-Fiber (RFoF) technology is then supported by the necessity to ensure radioastronomical signal fidelity over various distances. It also looks into optical transmitter selection, highlighting the use of DFB lasers over other types based on distortion, noise, cost, and power consumption. It is emphasized that the cost reduction in critical optical components, driven by commodity applications such as fiber-to-the-home, makes high-quality devices capable of operating at a few gigahertz quite affordable. The DFB lasers used are deemed appropriate for the SKA-low receiver system.

The part concludes by describing the first-generation RFoF links used for analogue transmission to the CPF, including the use of standard DFB lasers operating at 1310 nm and the use of wavelength division multiplexing (WDM) technology to transmit two antenna polarizations. The benefits of WDM, particularly coarse-WDM (C-WDM), are underlined in terms of cost and complexity reduction. Furthermore, the wavelength selection for SKA-low is explored in connection to optical attenuation and phase discrepancies between optical lines. Finally, due to the reduced levels of optical power carried by the fiber in the SKA-low scenario, the absence of normal fiber nonlinear effects is recognized.

1.3) SKA-Low Reciever Design

A careful review of numerous parameters is required to assess the practicality of Radio Frequency-over-Fiber (RFoF) for applications in radio astronomy. Gain and phase stability across temperature variations are among the essential metrics being examined, which include contributions from both the optical transmitter's electronics and the fiber optic cable. These parameters have a substantial impact on instrument performance and the frequency with which calibrations are necessary.

The various components of the SKA-low receiver have been thoroughly evaluated in consortium programs like as the Aperture Array Verification Program (AAVP) and the Aperture Array Design Consortium (AADC). These initiatives have been developed in collaboration with a number of institutions, including the Dutch Institute for Radio Astronomy (ASTRON), the Australian International Centre for Radio Astronomy Research (ICRAR), the University of Cambridge (UCAM), the Italian National Institute for Astrophysics (INAF), and the University of Bologna (UNIBO). Specific gain and phase stability issues have been thoroughly investigated and handled. Notably, the RFoF module built for prototypes and demonstrators like AAVS1, AAVS2, and EDA2 has been modified based on insights gathered from field campaign tests, resolving any design weaknesses discovered along the way.

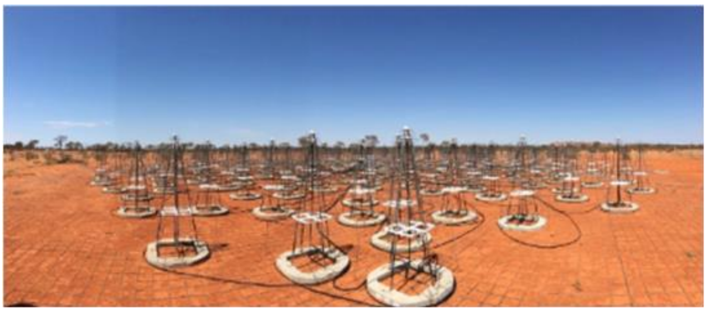

Figure 1.3(a): AAVS1 prototype stations deployed at the MRO, Western Australi

Figure 1.3(b): AAVS1 prototype stations deployed at the MRO, Western Australi

1.3.1) Structure of the SKA-Low Reciever and Tests of Compliance with SKA-low Specifications

The analog receiver is divided into three major components: the front end module (FEM), which houses the RF/optical transmitter, the optical fiber, and the pre-analog to digital unit (PREADU), which houses the optical/RF receiver. Notably, the RFoF link is fully integrated into the RF analog receiver chain, with active components such as WDM laser sources and WDM double PD being intrinsic to the FEM and PREADU circuits, respectively.

Two FEM installation solutions have been investigated and tested in the field using demonstrators. In the case of AAVS1 ,FEMs are placed at the antenna's apex, right after the low-noise amplifier (LNA). A hybrid fiber-optic and copper power line connects these FEMs to a central antenna power interface unit (APIU). FEMs for a cluster of antennas are contained within a box known as the tiny modular aggregation and RFoF trunk box (SMARTbox) for AAVS2 ,which is connected to the antennas by short coaxial cables covering roughly 10 meters. When compared to the initial AAVS1 concept, the current SMARTbox design, as implemented and tested with AAVS2, offers significant gains in terms of maintainability and accessibility.

To improve its functionality, the Front-End Module (FEM) integrates various components. Notably, it has a high-pass filter with a 3-dB cut-off frequency about 35 MHz. This filter is critical in removing powerful Radio Frequency Interferers (RFI) that are present within its stop band. The FEM also includes an in-line bias-T to give power to the Low-Noise Amplifier (LNA), an RF amplifier, and a laser, as well as an automatic optical power management circuit. The two polarization signals act as direct modulators for the laser currents operating at 1270 and 1330 nm in the overall scheme depicted in Figure 1.3.3. These modulated signals are then concatenated onto a single optical fiber for each antenna and sent from the field node to remote acquisition systems.

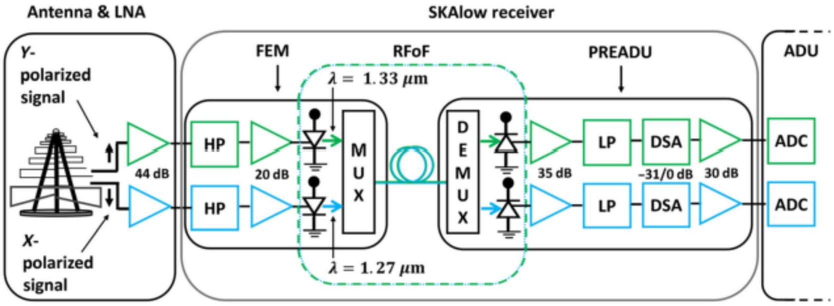

Figure 1.3.1: SKA-Low Reciever

1.4) Thesis Scope

This thesis covers the development, application, and assessment of a compensation scheme for amplitude variations in radio astronomy setups. The thesis specifically focuses on the creation and implementation of an advanced Radio-over-Fiber (RoF) system that can track and adjust for amplitude variations brought on by external factors. The thesis's main goals are as follows:

- Design and Implementation of Compensation System:
    - Creating a compensation system for radio astronomy systems to mitigate amplitude fluctuations brought on by outside variables like temperature changes.
    - Developing and putting into practice cutting-edge compensation strategies to stabilize signal amplitudes and improve measurement accuracy.
- Improved Radio-over-Fiber (RoF) System:
    - Creating and implementing a cutting-edge RoF system that can be easily integrated with the current infrastructure for radio astronomy.
    - Establishing a foundation for long-distance optical signal transmission that minimizes amplitude distortions and maintains signal integrity.
- Comprehensive Experimental Evaluations:
    - Carrying out extensive testing in a range of environmental settings to evaluate the system's endurance in sustaining signal correctness and stability.
- MATLAB-Based Control and Monitoring:
    - Creating control algorithms with MATLAB to coordinate the functioning of the compensation system and track important variables in real-time.
    - Utilizing MATLAB's adaptable framework for signal processing, control, and data collecting to develop adaptive compensation systems suited to certain environmental circumstances.
- Comparative Analysis and Interpretation of Outcomes:
    - Conducting a comparative analysis of experimental outcomes acquired with and without compensation to assess the efficacy of the compensation system.
    - Analyzing data trends, locating signal stabilization zones, and making judgments about the robustness and effectiveness of the system.

- Integration of Multidisciplinary Approaches:
    - Integrating elements of electrical engineering, optics, signal processing, and radio astronomy in a multidisciplinary approach.
    - Seeking to improve the quality and dependability of astronomical observations by addressing problems caused by amplitude fluctuations in radio astronomy systems and advancing instruments and measuring methodologies.

CHAPTER 2

2.1)Gain Response

In order to ensure that any variations in data output are due to the observed sky rather than the measuring device, science data processing and analysis procedures require stable signal chains throughout all recorded data samples throughout an observation. Since calibration involves changing the signal chains to standardize and optimize their behavior at a particular moment in time, it is a crucial stage in this process. It is imperative to sustain this conduct amidst reference measurements, preferably for extended durations, to ensure data coherence and minimize expenses associated with procuring and handling calibration data.
The main idea behind practical calibration techniques is to compare each signal chain's response to a common reference signal. In order to achieve the intended, or at least comparable, gain behavior throughout the whole band, this entails adjusting or offsetting their actual complex transfer functions. Reference measurements, however, are reliant on sufficient input signals being available.

It was once believed that creating local reference signals with the necessary accuracy would be unfeasible due to the high number of independent signal inputs. All antennas, however, use the sky itself as a ubiquitous input signal, which, when processed appropriately, can function as a useful calibration reference. This innovative approach not only addresses cost concerns, but it also increases the workflow's dependability and efficiency by calibrating using an intrinsically accessible and consistent signal source. The new application of calibration processes in the context of signal processing and analysis in scientific observations is highlighted by incorporating this information into my thesis.

By dissecting the transfer function into terms associated with distinct driving functions, it is possible to precisely change it by a combination of end-to-end measurements and modeled effects. In addition to reducing the requirement for in-the-moment sky-based readings, this enables statistical analysis that may enhance the system's long-term stability.

The stability requirements of the system are affected by the time scales of environmental variations and testing techniques, as well as the need for scientific precision. Whereas the local thermal time constants of electronic components operate on a minute scale, environmental effects exhibit 12- and 24-hour periodicities. Moreover, recalibrating intervals of around 10 minutes are required for ionospheric perturbations. The capacity to record large-scale events such as the Sun and galaxy is made possible by the enormous field of view of individual antennas, but this also limits the availability of direct interferometric calibration at particular times. Therefore, a hybrid solution combining advance modeling with sporadic on-sky measurements is required to meet the calibration requirements of the SKA system.

Temperature variations in the surrounding environment are the primary cause of changes in transfer functions, particularly in gain, according to the signal chain analysis. The architectural design of the SKA reduces the impact on the optical fiber, the Front-End Module (FEM), and the Low Noise Amplifier (LNA) by carefully putting electrical components in dependable processing facilities. In the ensuing sections, I will elaborate on the specific functions that the optical fiber and FEM perform in the signal chain variations.

2.2)Amplitude stability due to the FEM temperature only

A thorough characterization was carried out in the lab using a climatic chamber to investigate the effect of temperature exposure on the overall stability of the FEM. This required changing the temperature from -10 to +80 degrees Celsius. The results, shown in Figure 2.2.1, display measurements taken from a sample of six FEMs used in the AAVS2 manufacture. These results demonstrate differences in absolute gain between the 1270- and 1330-nm channels, indicating a steady decline with temperature, highlighting the need to restrict the FEM's maximum operating temperature to +65°C during the day.

Furthermore, the results in Figure 2.2.1 demonstrate that the necessary gain threshold (41dB) can be reached throughout the entire temperature range with the right DSA adjustment. For all measured devices, regardless of supplier, the gain decrease for the 1270-nm channel is consistently greater than that of the 1330-nm channel, attributed to the orientation of the optical carrier at 1270 nm, which requires reflection by the WDM thin film filter instead of transmission, as the 1330 nm carrier does. As a result, the 1270-nm channel is more vulnerable to mechanical stresses brought on by variations in package assembly temperature.

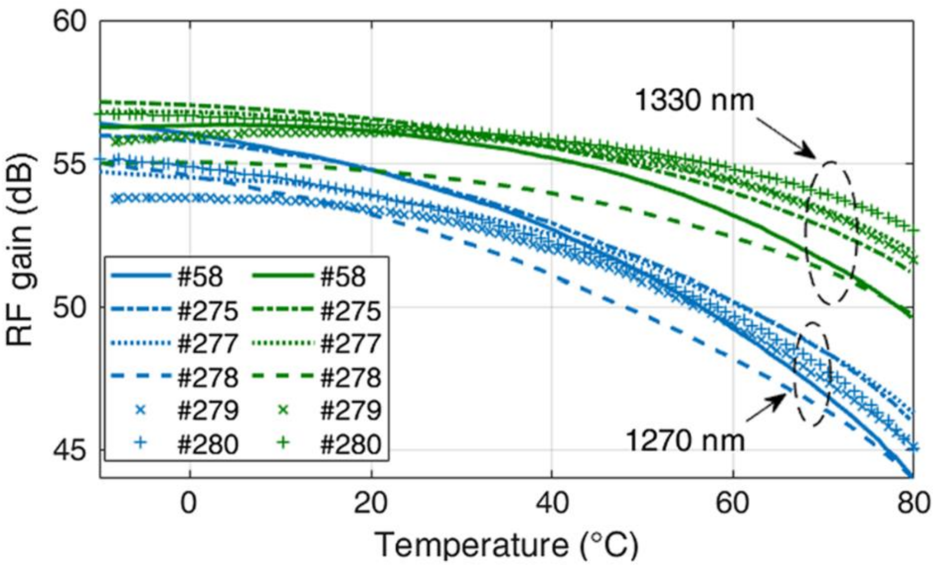

Figure 2.2: Illustrate necessary gain threshold

Because of the SKA-low system's environmental circumstances, typical thermalization techniques are not feasible due to issues with cost and power consumption. Thus, it becomes critical to minimize phase errors, which calls for cautious component selection.

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2.3)Amplitude stability due to the fiber temperature only

Direct field measurements of Radio Frequency over Fiber (RFoF) links were conducted at the Murchison Radio-astronomy Observatory (MRO) between 2014 and 2016. These measurements encompassed various fiber-optic cables, some several kilometers long, installed underground or above ground, and subjected to temperature variations. Two types of cables were examined: the standard loose-tube fiber cable for the AAVS2 project and the AFL spider web ribbon (SWR) cables utilized in the AAVS1 project. The aim was to assess the impact of environmental exposure on signal stability by evaluating magnitude fluctuations of RF-modulated optical signals transmitted over the cables.

The experimental setup involved a multiport vector network analyzer (VNA), real AAVS Wavelength Division Multiplexing (WDM) RFoF modules, and several cables. S-parameters (amplitude) of the RF signal from two fiber-optic cores located at opposing ends of the cable assembly's cross-section were measured. Each fiber transmitted two wavelengths (1270 and 1330 nm), resulting in four sets of S-parameters from two RFoF modules.

Measurements were conducted on a 24-hour schedule, with a 10-second gap between successive readings, using four VNA channels covering the SKA-low frequency spectrum (50 to 350 MHz). The VNA, RFoF modules, and temperature-controlled server rack were placed indoors to mitigate temperature-induced variations.

The findings from the field tests indicated that phase stability of RF signals transmitted over the fiber optic cable was primarily influenced by external exposure. Analysis revealed that thermal fluctuations on the cable, associated with environmental conditions, significantly impacted phase stability. Subterranean burial was identified as a method to reduce temperature changes in the cable, resulting in improved stability compared to surface-laid cables.

2.4) Mitigation to Rayleigh Backscattering

A SKALA4-AL antenna and an EDA2 dipole were installed at the Murchison Radio-astronomy Observatory (MRO) during a site visit in November 2018, designated as phase 0. The fiber connection used for AAVS1 was used to connect these antennas to a dedicated Test Point Module (TPM) located in the ASKAP control facility. Two concerns have been detected since the first acquisitions, one linked to noise and the other to distortion terms.

To begin, both the EDA2 and SKALA4 antennas had noise floor changes, with occasional high peaks. These anomalies were more visible at lower frequencies (50 MHz), but they were prevalent over the whole SKA-low band (50 to 350 MHz).

In addition, during a laboratory analysis of the lone RFoF link, a surprising behavior was discovered. This behavior was constant for both wavelengths (1330 and 1270 nm), which conveyed the antenna's Y-polarized and X-polarized RF signals, respectively. The unusual feature entailed determining the intercept point of the link's second order (IP2). The power of the second harmonic distortion component (HD2) was unexpectedly significant when the link was directly manipulated with a sinusoidal tone. Furthermore, these values increased as the modulating tone's power decreased, revealing an unanticipated link.

Rayleigh optical backscattering has been identified as the root cause of both difficulties. The interaction between the light emitted by the laser and the light back-reflected by the fiber into the laser cavity causes this phenomena. As a result, the optical isolator included into the optical source has a substantial influence on the magnitude of this effect. Due to the close proximity of the used wavelengths (1270 and 1330 nm, respectively), the negative impact is consistently detected in both RFoF connections dedicated to X- and Y-polarization signals.

This method, known as the dithering tone technique, has previously been proposed to reduce interferometric noise in optical fiber systems, particularly noise caused by Relative Intensity Noise (RBS). The major goal of this technique is to reduce noise levels, particularly at lower frequencies.

In addition, a thorough theoretical and practical examination was carried out to comprehend the counterintuitive behavior found in the spurious frequencies created at the receiving end of the Radio Frequency-over-Fiber (RFoF) system when subjected to a sinusoidal modulating tone. This analysis resulted in a full explanation of the observed behavior, and it was determined that the dithering tone approach may serve as an effective countermeasure to lessen the overall influence of system nonlinearities based on these theoretical conclusions.

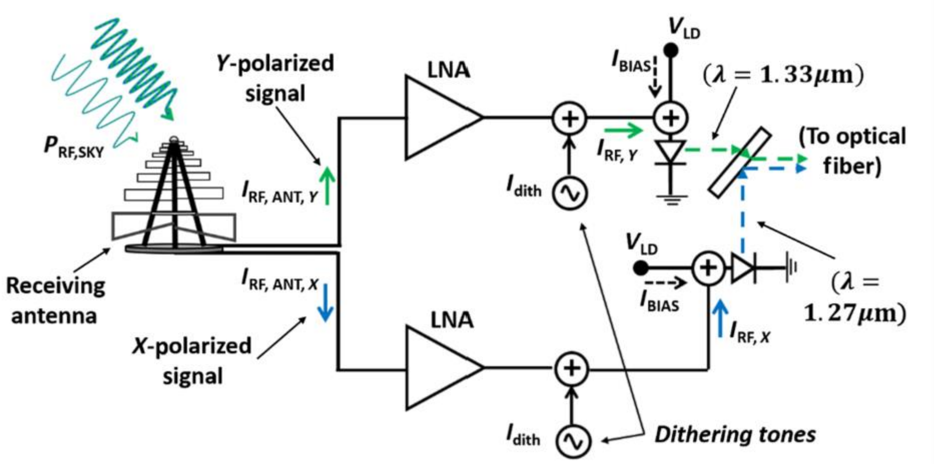

Figure 2.4.1: Simplified scheme depicting the introduction of the dithering tones in each of the two RFoF transmitters utilized in the receiving chain of AAVS2

Figure 2.4.2 depicts the RFoF system's performance, focused on the creation of HD_2, which reflects the power received at twice the frequency ($2f_{RF}$) of the modulating tone frequency. When the power level (P_{RF}) exceeds a particular threshold, the laser's nonlinearity becomes the major source of HD_2, regardless of the modulating tone's frequency (f_{RF}). This produces an intuitive link in which higher modulating current amplitudes result in higher HD2 values. the opposite is true, when the modulating frequency f_{RF} falls within the range of 10 MHz to slightly above 350 MHz (encompassing the SKA-low band of 50 to 350 MHz), and the Radio Frequency Power (P_{RF}) is progressively reduced from 0 dBm to lower values, the second harmonic distortion (HD_2) exhibits a non-monotonic behavior. Specifically, it initially decreases, followed by a counterintuitive increase, reaching a maximum value , and finally undergoes a subsequent decrease.

This behavior is attributed to a combined effect of Relative Intensity Noise (RBS) and laser frequency chirp. Consequently, the HD_2 behavior is shown to be dependent on the phase modulation index (M_{RF}), which is :

$$M_{rf} \propto \frac{Kf\sqrt{Prf}}{\sqrt{Frf}}$$

Where K_f represents the adiabatic chirp coefficient of the laser utilized. It is important to note that this phenomenon applies to all possible spurious frequency terms received by the Radio Frequency over Fiber (RFoF) link.

As previously mentioned, the implementation of the dithering tone technique serves as an effective countermeasure to the nonlinear generation of spurious frequencies described above. This technique also addresses the undesired presence of noise peaks and noise floor jumps, observed predominantly for f_{RF}<50 MHz but present within the entire SKA-low bandwidth.

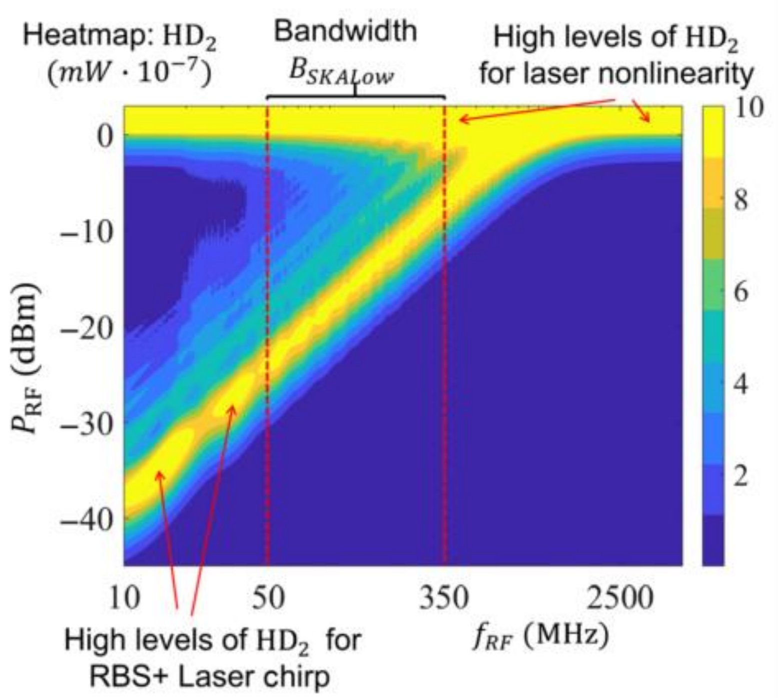

Figure 2.4.2: Behavior of the power received by the RFoF system at the frequency 2f RF

Figures 2.4.3(a) and 2.4.3(b) depict the positive impact on signal quality received over the Radio Frequency-over-Fiber (RFoF) link, particularly in terms of noise reduction. The shown bandwidth runs from 5 to 45 MHz, demonstrating the significant improvements brought about by the use of the dithering tone approach. The spikes are clearly apparent in the live spectrum (represented by the yellow trace) in picture 1.4.3(a), whilst the noise floor jumps appear as horizontal stripes in the spectrogram (given in the lower portion of the picture).

The absence of spikes in the live spectrum and the removal of horizontal stripes in the spectrogram in Figure 2.4.3(b) clearly demonstrate the efficiency of introducing the dithering tone into the system. This discovery emphasizes the dithering tone technique's beneficial effect on noise reduction in the RFoF link.

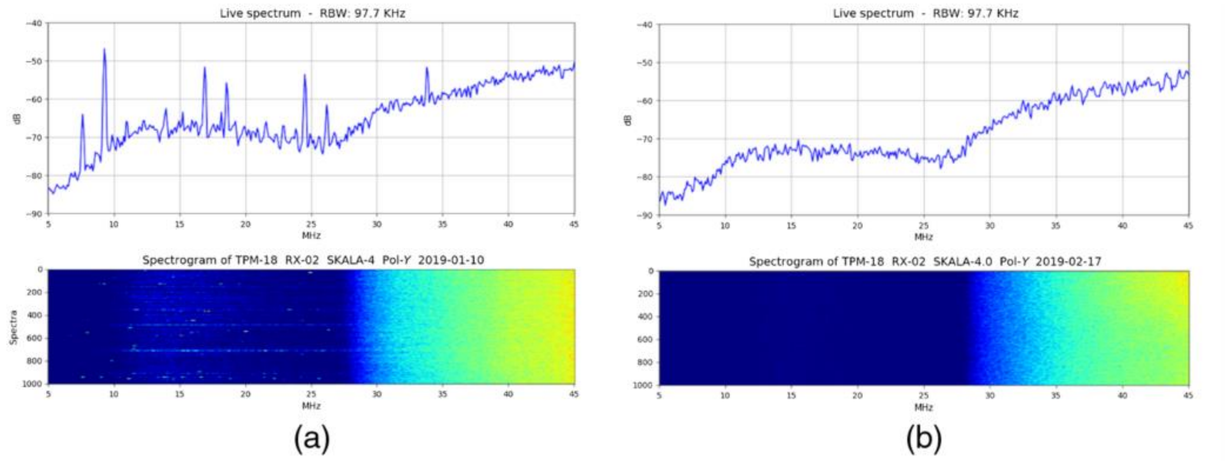

Figure 2.4.3: Captured live image of the measured spectrum of the power received by the RFoF system in the bandwidth range 5 to 45 MHz (b) with and (a) without dithering.

Figure 2.4.4 depicts the influence of the dithering tone on the output intercept point of the second order (OIP2) in addition to its effect on spikes and noise. The graph shows a significant improvement, particularly at low frequencies.

However, it is important to note that the insertion of the dithering tone, which directly modulates the laser, has the potential to cause intermodulation distortion. This distortion must be carefully controlled to keep its impact within acceptable bounds. To set a specification for the highest permitted level of intermodulation, it is critical to keep this level below the noise at the receiver's output, taking into account SKA-low's finest bandwidth of 266 Hz. For example, while evaluating the most potent Radio Frequency Interference (RFI) from the Orbcomm satellite at 160 MHz and assuming the use of the SKALA4 antenna, an intermodulation product of at least 50 dB is required to prevent the system from recognizing it

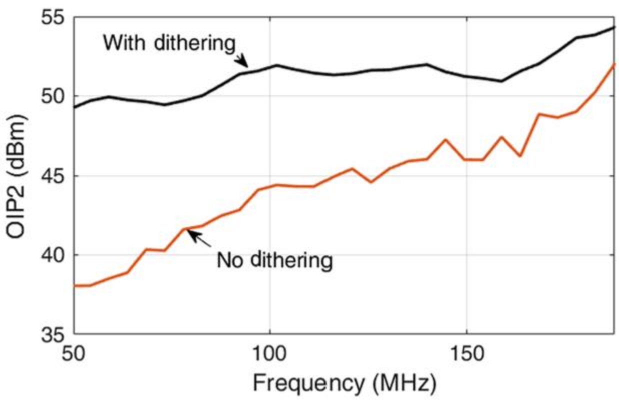

Figure 2.4.4: Example of behavior of the OIP2 for the 1330-nm wavelength of the RFoF link employing 6 km of fiber span.

CHAPTER 3

3.1) Project Overview and Methodology

This chapter presents the thesis project's comprehensive approach as well as its general framework. The principal aim of this research project is to develop a compensation system for amplitude fluctuations (FCS) caused by external factors, with a focus on temperature-related gain fluctuation. In addition, to monitor and correct amplitude fluctuations in radio astronomy systems induced by external agents, an improved Radio-over-Fiber (RoF) system is being developed and installed.

The project's general aims and objectives are explained at the outset of this chapter, along with the need of compensating for temperature variations in gain and the importance of handling amplitude fluctuations in radio astronomy systems. Developing efficient compensating solutions is crucial because gain variability is a considerable challenge to preserving the quality and reliability of radio astronomy data.

The process used to accomplish these goals is then carefully described, including a number of phases from ideation to execution. The project's methodology follows a methodical approach that starts with a thorough analysis of the body of knowledge and relevant studies in the fields of compensation systems, radio astronomy, and RoF technology. Special attention is paid to gain fluctuation mitigation techniques.

The research methodology moves from the literature study to the design and development phase, when new algorithms and techniques are developed to reduce amplitude fluctuations, including temperature-induced gain variations. This stage combines theoretical models with real-world issues, using sophisticated software frameworks and simulation tools to improve the suggested fixes.

The approach for implementation is explained in the next sections, which include the deployment of prototype systems and experimental setups to verify the effectiveness of the suggested compensation system and RoF increases in reducing temperature-induced gain fluctuations. This calls for a methodical testing, iteration, and refining process that is informed by analytical insights and empirical data.

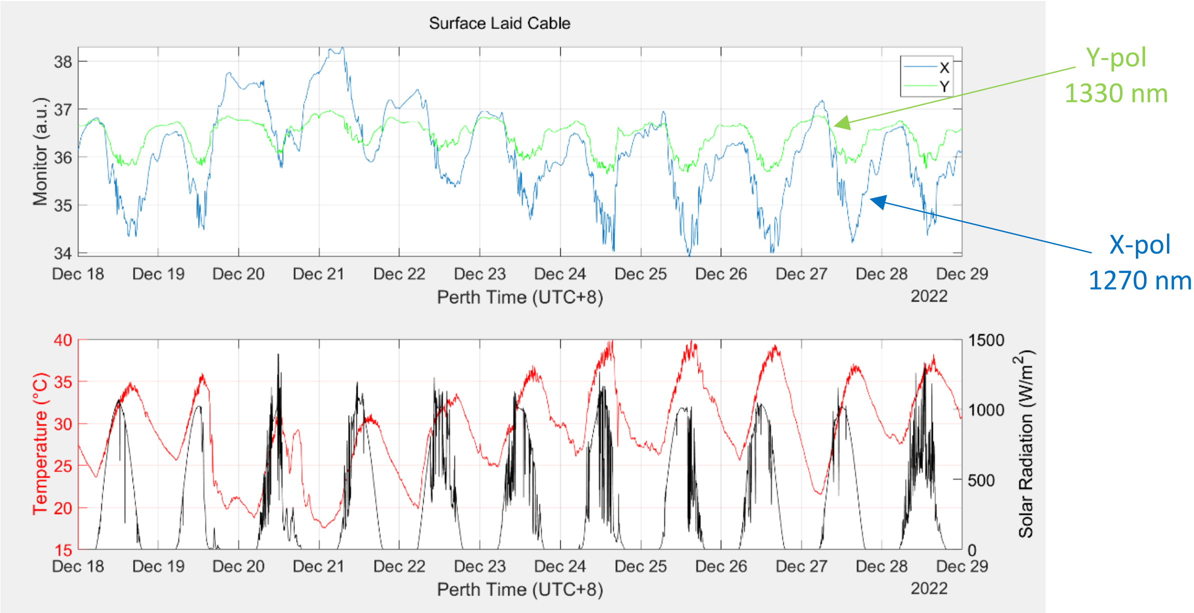

Figure 3.1 : Ten days of on-site measurements of both X and Y polarization and measurements of solar radiation and temperature.

Additionally, this chapter offers insights into how the compensation system and RoF upgrades fit into the current radio astronomy infrastructure, emphasizing compatibility, scalability, and operational feasibility points. Furthermore, a graphical depiction of the amplitude fluctuations, including gain variations, is shown in Figure 3.1, which highlights the difficulties this research endeavor attempted to address. By systematically addressing the problem of temperature-induced gain fluctuation, this research endeavor hopes to advance radio astronomy instrumentation and open the door to improved observations. This will be achieved through a comprehensive approach that includes design, development, implementation, integration, and literature review.

3.2) Voltage Variable Attenuator (VVA) Based Compensation Technique for Amplitude Fluctuations

The rationale behind the creation of a voltage variable attenuator (VVA)-based compensation method will be presented. A viable solution to amplitude fluctuations in radio astronomy systems caused by external factors—specifically, variations in gain resulting from temperature shifts—is to employ VVA. The objective is to improve the precision and stability of signal transmission by using a VVA-based compensation technique, which will increase the dependability of radio astronomy observations.

The conceptual framework and essential elements involved in reducing amplitude fluctuations are depicted in Figure 3.2, which offers an overview of the basic idea behind the Fluctuation Compensation System (FCS). This diagram clarifies the function of VVA in controlling signal attenuation to successfully offset amplitude changes and provides insights into the complex dynamics of the compensation process.

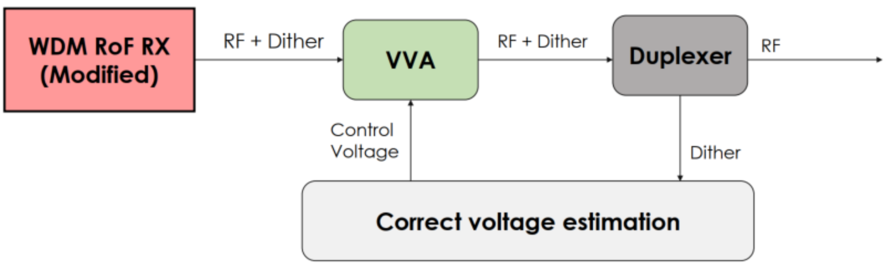

Figure 3.2 Closed Loop control feedback circuit contain voltage variable attenuator

Additionally, a pilot tone with a frequency of 8.5 kHz is incorporated in the application of this compensatory procedure. As a reference signal, the pilot tone allows for real-time monitoring and VVA setting adjustment to preserve signal stability in the face of environmental variations. The compensation system can adjust dynamically to changing conditions by utilizing the pilot tone feedback mechanism. This ensures optimal performance and reduces the effect of amplitude variations on radio astronomy observations.

This research project aims to improve the state-of-the-art in amplitude fluctuation mitigation strategies by integrating a pilot tone feedback mechanism and a VVA-based compensation technique. This would ultimately improve the accuracy and dependability of radio astronomy equipment. The technical aspects of the compensating technique, such as the design considerations, implementation strategy, and experimental validation, will be covered in later parts. These sections will also clarify the practical consequences and effectiveness of the suggested approach.

3.3) Advanced Attenuator Modeling and Circuit Design

A thorough investigation of the T-PAD attenuator model—which includes a pseudomorphic high electron mobility transistor, or P-HEMT—will be conducted in the next portion of this chapter. The T-PAD attenuator model is a key element of the compensation technique framework, providing an advanced way to control attenuation of the signal dynamically in response to changes in the environment, especially temperature variations.

The complex architecture and working principles of the T-PAD attenuator model will be thoroughly examined in this section.

It will specifically explain the intricate relationship between the P-HEMT transistor and the attenuator circuitry, highlighting how the special qualities of the P-HEMT transistor are used to achieve accurate and flexible control over signal attenuation. This talk will cover the basic theoretical underpinnings, design issues, and technical nuances of implementing a responsive and effective attenuator model that can handle the amplitude variations present in radio astronomy equipment.

In addition, a detailed analysis of the Voltage Variable Attenuator (VVA) circuit model, which was painstakingly constructed inside the AWR application, will be showcased. This circuit model functions as a virtual blueprint and provides a wealth of information on the internal mechanisms and functional design of the VVA.

This section will explain the structure of the VVA using both schematic and detailed diagrams. It will emphasize how the signal pathways, control mechanisms, and electronic component layout are arranged to allow for dynamic signal attenuation in response to external stimuli.(Figure 3.3.1)

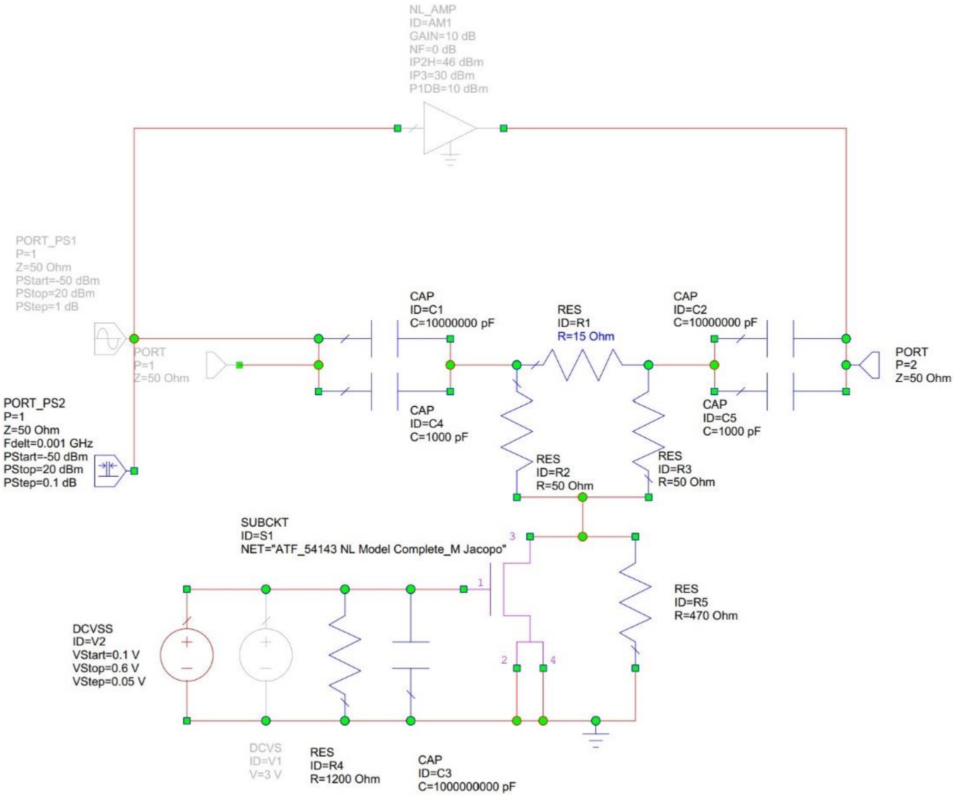

Figure 3.3.1 : Schematic of VVA – AWR

Additionally, a thorough comparison study of the S-parameter plots from AWR simulation and laboratory research will be included in this part. This comparative analysis is an important validation exercise that confirms the AWR simulation model's accuracy and faithfulness in simulating real-world performance. This investigation provides a rigorous assessment of the simulation model's prediction power and appropriateness for directing realistic implementation methods by contrasting empirical data with simulated results.(Figure 3.3.2)

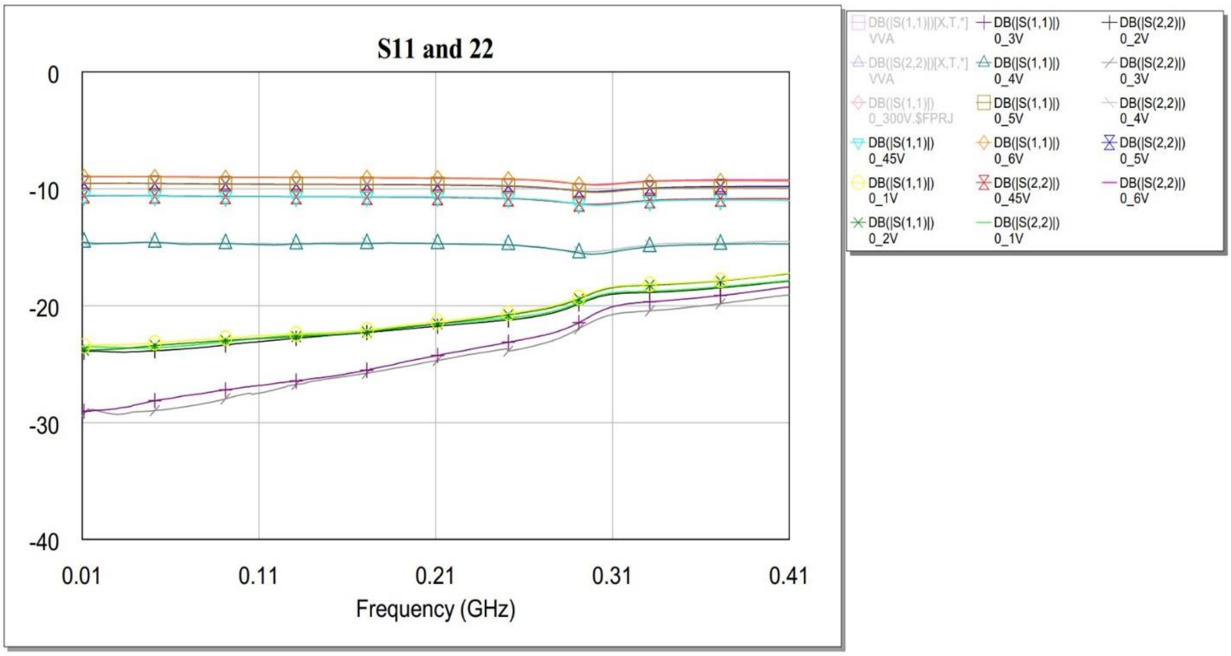

Figure 3.3.2 (a) demonestrate overlaping measured S11 and S22 parameters in Lab w.r.t S-parameter data from VVA design in AWR software

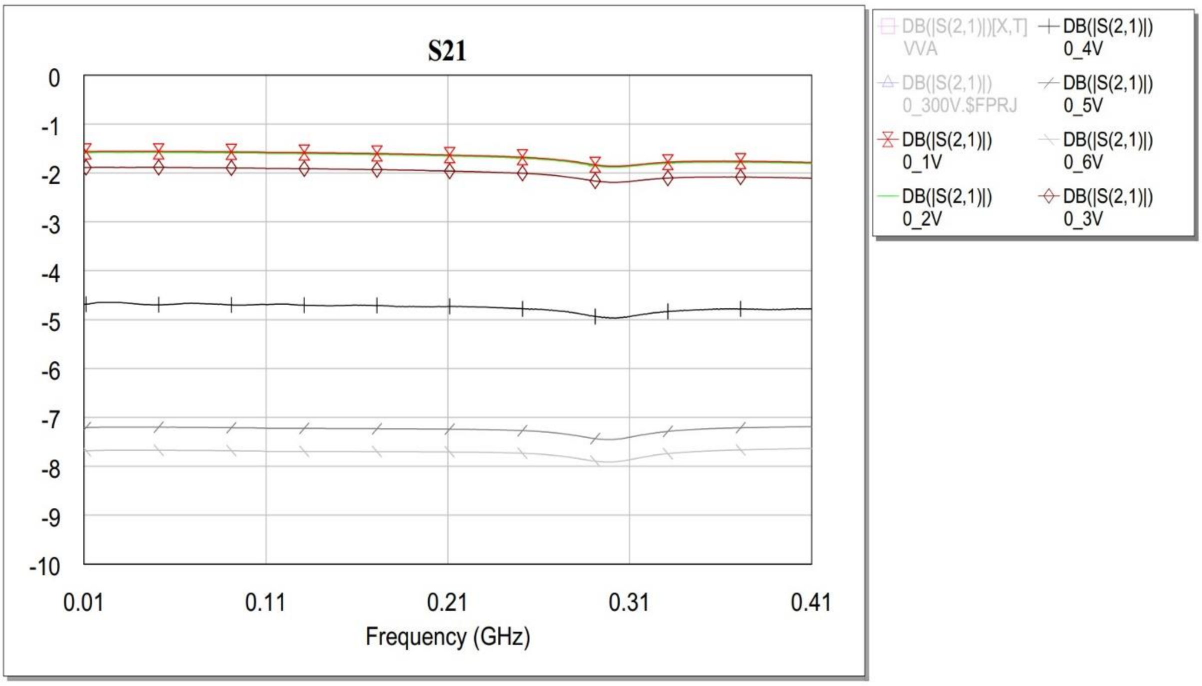

Figure 3.3.2 (b) illustrate how the S-parameter data from the VVA design in AWR software overlaps with the measured S21 parameters in the lab.

3.4) Characterization of Voltage Variable Attenuator (VVA) Operational Region

Using the acquired data, a detailed diagram representing the VVA's operational area has been produced. This figure concisely illustrates the VVA's dynamic response and attenuation capabilities over the specified frequency range of 50 MHz to 400 MHz. The figure functions as a visual assistance by giving a precise representation of the performance characteristics of the VVA under various operating situations.

The operational envelope of the VVA is shown in Figure 3.4, along with its bandwidth, linearity, and attenuation range. Based on a thorough examination of the data obtained from the VNA Planar device, this figure provides important information about how precisely and accurately the VVA can control signal attenuation. Furthermore, it offers a graphical representation of the VVA's operating boundaries, making it easier to comprehend how well it performs in various frequency ranges.

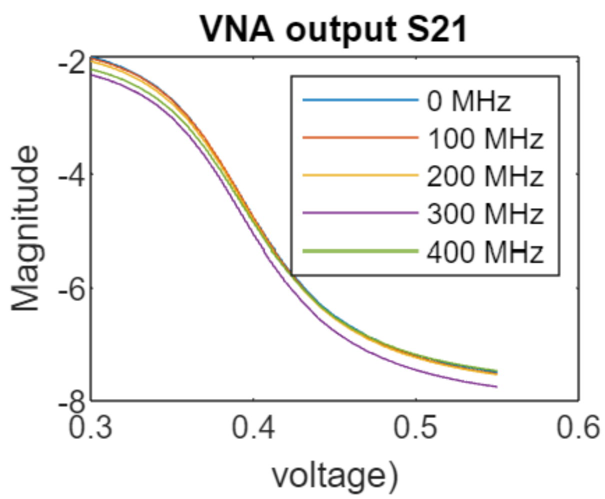

Figure 3.4 Represent characterization result of voltage variable attenuator and indicate operation range of VVA

A thorough grasp of the VVA's functionality is attained by combining the visual depiction of its operational area with the analytical knowledge gained during the characterization procedure. Informing following design iterations and implementation tactics, this figure plays a crucial role in the assessment and validation of the VVA's performance within the larger framework of the compensation system.

3.5) Test Bench

To enable regulated temperature modulation of the laser in the transmitter side, a full test bench was established in the experimental setup. The Peltier module, which was carefully incorporated to control the laser's temperature, was the centerpiece of this arrangement. This module allowed for the creation of a thermal chamber and allowed for precise control over the laser temperature. It was driven by a direct current (DC) power supply.

RTD 4-wire sensors were used, carefully coupled to a digital acquisition device, to monitor and control the temperature. Because of the precise temperature readings provided by this setup, the Peltier module may be controlled in real-time to maintain the appropriate laser temperature within predetermined bounds.

In addition, the laser's input configuration included a blend of radio frequency (RF), DC, and dither tone signals. Using a bias tee, the dithering tone which is essential to the compensation technique was smoothly and externally created and connected with the RF signal. Because of this integration, it was easier to inject the dither signal into the RF route and compensate dynamically for amplitude fluctuations caused by outside causes.

The arrangement of the test bench was carefully thought out to provide a stable and regulated setting for research experiments. Through the use of temperature control, accurate signal conditioning, and integrated dithering, the system offered a flexible means of assessing the effectiveness of the compensation method in reducing amplitude variations in radio astronomy systems.

The entire configuration of the test bench is depicted in Figure 3.5, which also highlights the complex connectivity of subsystems and components. This graphic depiction provides an understanding of the experimental configuration by emphasizing the incorporation of signal conditioning, temperature control, and dithering features that are necessary for carrying out thorough experimental assessments.

A favorable environment was created for conducting methodical experiments to confirm the effectiveness of the compensation technique in reducing amplitude fluctuations brought on by temperature variations and other external factors through the careful design and implementation of the test bench.

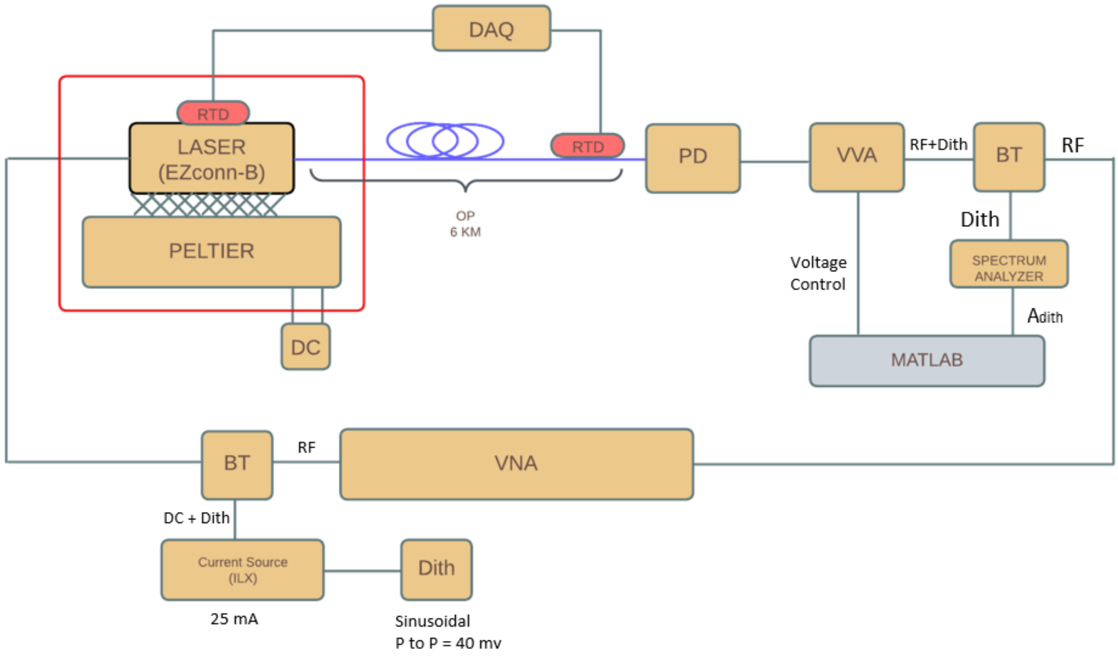

Figure 3.5 Schematic depiction of the test bench setup showcasing the integrated components for temperature control, laser modulation, RF coupling, and real-time monitoring.

The main receiver element in the experimental setup's receiving side was a passive photodetector. With appropriate system integration, this photodetector allowed incoming optical signals to be converted into electrical signals for additional processing and analysis. The photodetector, a crucial link in the receiver chain, was vital in catching the modulated optical signal that was given out by the laser source.

Most importantly, MATLAB was used to coordinate the implementation of a closed-loop control system on the receiver side. The purpose of this control loop is to track the amplitude of the dithering tone that is present in the received signal continually. The control loop extracted essential information about the dithering tone amplitude by processing the incoming signal data in real-time and utilizing MATLAB's robust computational capabilities.

The MATLAB control algorithm dynamically modified the control voltage delivered to the Voltage Variable Attenuator (VVA) in the receiver chain based on the retrieved amplitude data. Through the use of an adaptive control system, the VVA was able to stabilize the received signal and lessen the effects of environmental disturbances by automatically compensating for any amplitude changes brought on by outside causes.

The VVA and the MATLAB-controlled feedback loop were integrated, demonstrating a highly advanced method of dynamic signal compensation. The system demonstrated remarkable adaptability and resilience to external disturbances by consistently monitoring the dithering tone amplitude and modifying the VVA control voltage correspondingly. This ensured the fidelity and precision of the received signal under a range of operating situations.

This closed-loop control design highlighted the adaptability and scalability of the experimental setting in addition to demonstrating the efficacy of the compensating technique. The receiver side control loop laid the groundwork for advanced applications in radio astronomy instrumentation and beyond by providing a strong framework for real-time signal processing and compensation through its smooth interaction with MATLAB.

3.6) MATLAB Code

The first part of the MATLAB code focuses on connecting the many components that are essential to the experimental setup. Using the General Purpose Interface Bus (GPIB) connection type, this step entails the careful configuration and integration of devices to guarantee smooth control and communication inside the experimental framework.

The block diagram in Figure 3.6 provides an organized summary of the architecture of the MATLAB code, showing how various components are connected and what their functions are. This graphic depiction acts as a guide for comprehending the complex connections between MATLAB control commands and devices.

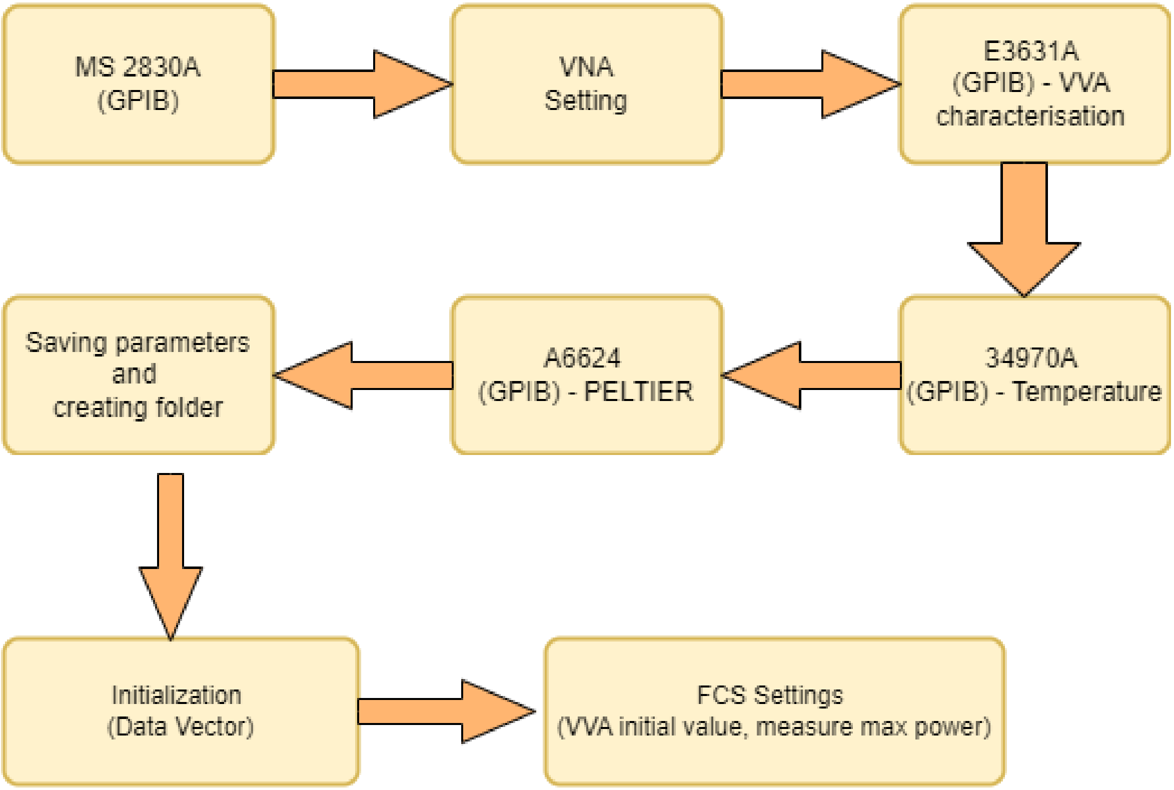

Figure 3.6 Block diagram illustrating the MATLAB-based control system architecture, encompassing device connectivity, compensation algorithms, and real-time monitoring for signal stabilization.

Establishing communication channels with necessary hardware components, such as the DC power supply in charge of operating the Voltage Variable Attenuator (VVA), is the first step in the configuration process. Through the definition of suitable parameters and settings,

MATLAB creates two-way communication with the DC power supply, allowing for accurate VVA voltage setting control.
The Digital Acquisition (DAQ) device, which is responsible for reading temperature information from RTD sensors, then comes into focus. In order to provide precise temperature readings, MATLAB configures input channels and acquisition parameters and coordinates the connection with the DAQ device. In order to make dynamic compensatory changes, this phase guarantees real-time monitoring of temperature variations.
The integration of a DC power source, which regulates the Peltier module that controls the laser temperature, is another crucial component of the configuration phase. Through the device's MATLAB interface, environmental conditions can be simulated by varying the temperature inside the thermal chamber.
Additionally, MATLAB establishes parameters for data logging and result storage, generating a specific folder structure to methodically arrange analysis outputs and experimental data. This makes sure that experimental results are managed and retrieved efficiently for further analysisreporting.
Once the device is connected and configured, MATLAB starts to collect data from the Vector Network Analyzer (VNA), obtaining important signal characteristics for further examination. This stage establishes the foundation for analyzing signal properties and rating the compensation system's effectiveness.
The Fluctuation Compensation System (FCS) is finally initialized by MATLAB, which sets parameters like the initial VVA value and measures the maximum power of the dither tone. By adjusting these parameters, the compensation system is primed for use, calibrated, and prepared to carry out dynamic amplitude fluctuation compensation in real-time.
By carefully planning this configuration procedure, MATLAB creates smooth communication and control over the wide range of hardware components in the experimental setup. This creates the groundwork for the successful application of the compensation technique and the gathering of copious amounts of data for further analysis.

3.7) Compensation Loop

The whole compensation loop which is divided into two separate sub-loops, the heating sub-loop and the cooling sub-loop is presented in the next section of the MATLAB code. These sub-loops coordinate the dynamic management of the Peltier module's temperature control, emulating ambient variations in real time and facilitating a thorough assessment of the effectiveness of the compensating system.

The overall design of the compensation loop in the MATLAB code is shown by the block diagram shown in Figure 3.7. This graphic representation provides an easy-to-understand explanation of the sequential operation of the heating and cooling sub-loops in addition to the iterative simulation technique used to evaluate the long-term performance of the system. By turning on the Peltier module to reduce the laser temperature inside the thermal chamber, the cooling sub-loop starts the temperature modulation process. The Peltier module's power supply is precisely adjusted using MATLAB commands, which also ensure that the atmosphere cools gradually to replicate temperature drops that are experienced in real-world circumstances.

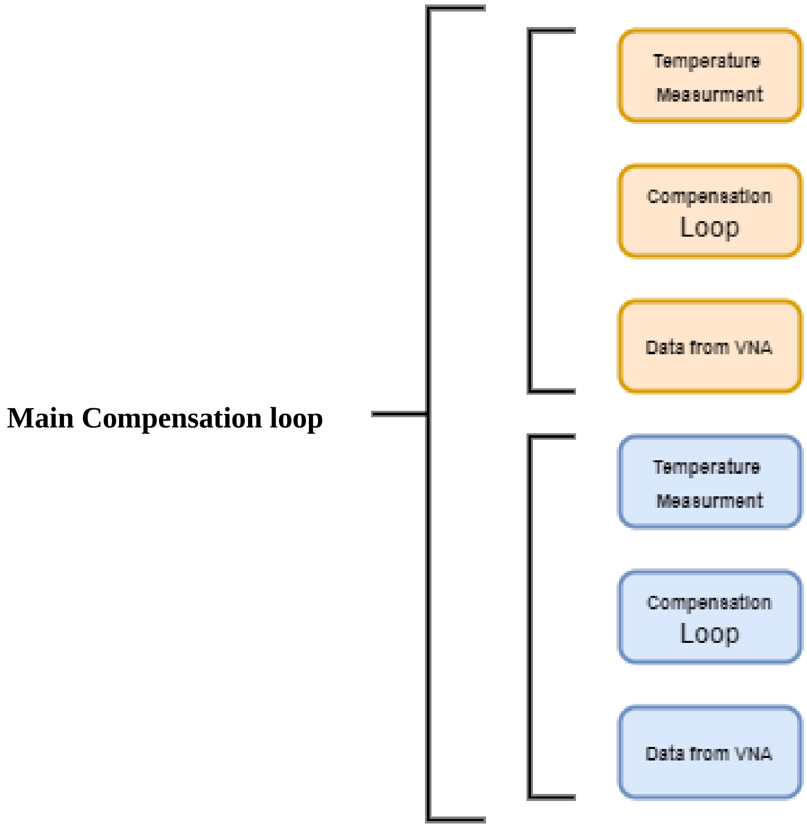

Figure 3.7 Representation of the main compensation loop detailing the iterative process for temperature stabilization, signal measurement, and feedback control to ensure signal amplitude consistency.

The Peltier module's power supply is dynamically adjusted by MATLAB commands to create regulated heating, simulating temperature rises typical of environmental fluctuations.

One important aspect of the compensation loop is that it is iterative, meaning that it may be used to mimic various temporal conditions seen in real-time operation through repeated simulation runs. This iterative process is made easier by MATLAB, which gives users the ability to customize the length and frequency of simulation repeats. This allows users to evaluate the compensation system's performance across longer time periods.

Using feedback from the RTD sensors, MATLAB continually tracks temperature variations throughout the compensation loop to make sure the compensation system dynamically adjusts to shifting external conditions.

The compensation loop attenuates the effects of temperature-induced variations by stabilizing signal amplitudes through repetitive adjustments of the VVA control voltage based on temperaturefeedback.

The compensation loop assesses how well the compensation system maintains signal stability under dynamic situations by simulating real-time environmental changes through the coordinated operation of the cooling and heating sub-loops within the MATLAB code. This iterative method offers important insights into the robustness and long-term performance of the system in real-world radio astronomy applications.

3.8) Heating subloop

The Peltier module's temperature is controlled and ideal compensation performance is guaranteed through a series of carefully planned actions that are executed in the heating sub-loop of the compensation process. This part of the MATLAB code is essential for modeling temperature rises and assessing how the compensation system reacts to different temperatures. A organized overview of the heating sub-loop in the MATLAB code is provided by the block diagram shown in Figure 3.8, which shows the orderly execution of important phases and control mechanisms.

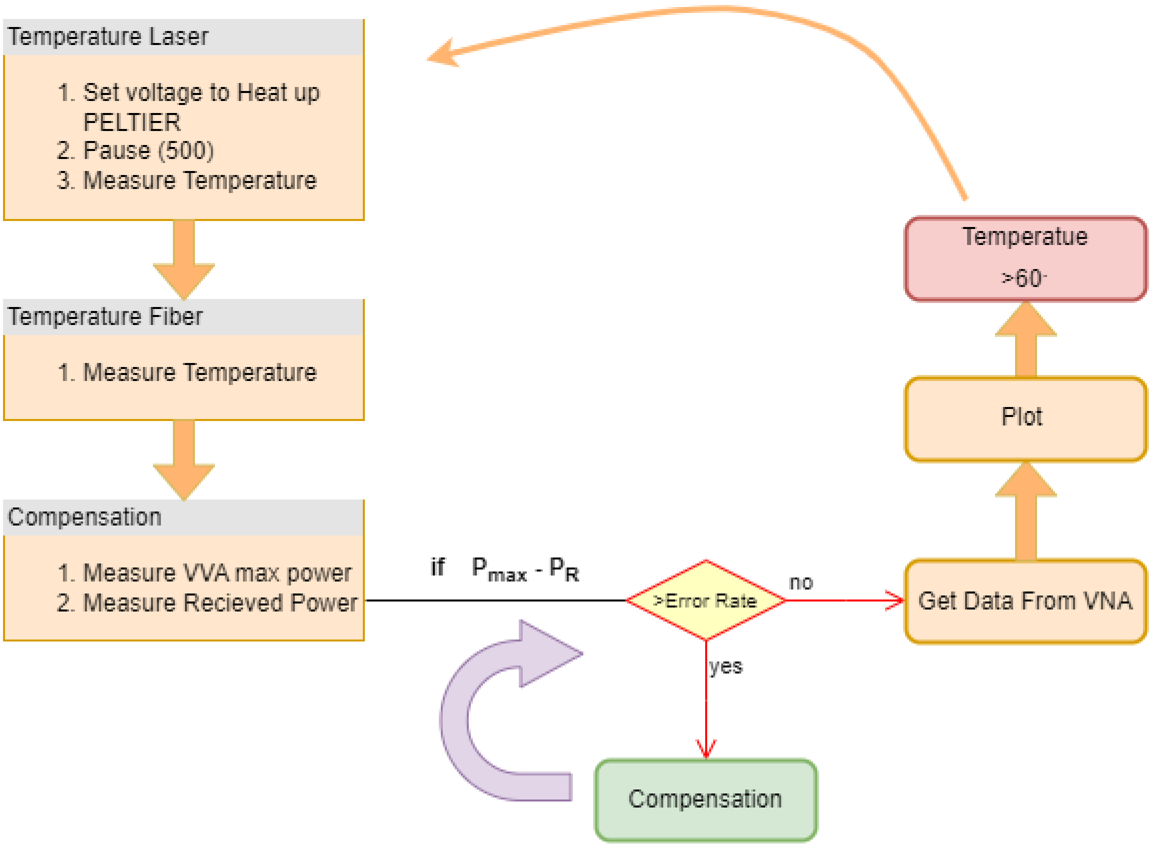

Figure 3.8 Illustration of the heating sub-loop depicting the sequential steps for temperature control, signal measurement, compensation, and safety protocols.

- Adjusting Peltier Module Voltage to Cause Controlled Heating:

  The first step in the heating sub-loop is to adjust the Peltier module's voltage to cause the thermal chamber to heat up gradually. The Peltier module's power supply is adjusted using MATLAB commands, progressively raising the laser environment's temperature.

- stability delay (500 Seconds):

  To allow for temperature stability, a 500-second delay is imposed when the Peltier module is activated. This time reduces transitory effects and makes reliable temperature measurements possible by ensuring that the laser and optical fiber attain equilibrium temperatures.

- Temperature Measurement:

  After that, the laser and optical fiber's temperatures are recorded. With the use of MATLAB commands, precise and accurate temperature data can be captured from the RTD sensors that are attached to the DAQ device.

- VVA Max Power (Initial Power) Measurement:

  The next stage is to determine the VVA's maximum power output (initial power). The collecting of VVA power data is made easier by MATLAB commands, which also serve as a baseline reference for any future compensating changes.

- Measurement of Received Power:

  To evaluate the effectiveness of the compensation mechanism, the received power is also measured concurrently. MATLAB commands measure the signal strength that the receiver receives by retrieving power data from the photodetector.

- Evaluation and Adjustment of Compensation:

  The first step in the compensation process is to determine the error rate between the measured received power and the maximum VVA power. In order to bring the received power into an acceptable range, MATLAB begins the compensation phase if the difference is greater than the predefined error rate threshold.

- Data Acquisition and Plotting:
  MATLAB gathers data from the Vector Network Analyzer (VNA) and creates output graphs that show the performance of the system if the error rate stays within allowable bounds. Plots like these provide information on signal properties and compensation efficiency.

- Temperature Safety Check (Not Exceeding 60°C):
  Lastly, a safety check makes sure that the laser environment's temperature stays below 60°C. Temperature readings are monitored by MATLAB instructions, and the code switches to the cooling sub-loop and halts execution if the threshold is exceeded.

The MATLAB code's heating sub-loop simulates temperature increases, assesses compensation performance, and guarantees operational safety in the experimental setting by carefully carrying out these procedures. Important insights about the system's resilience and functionality in dynamic temperature settings are obtained through this iterative procedure.

3.9) Cooling Subloop

The compensation procedure is carried out in the cooling sub-loop phase of the MATLAB code, which simulates temperature drops and evaluates the system's reaction to cooling dynamics. A structural structure resembling that of the heating sub-loop is preserved, but certain modifications are made to account for the special features of the cooling phase.
Outlined below are the key steps and modifications implemented in the cooling sub-loop, delineating its distinct role in the compensation process:

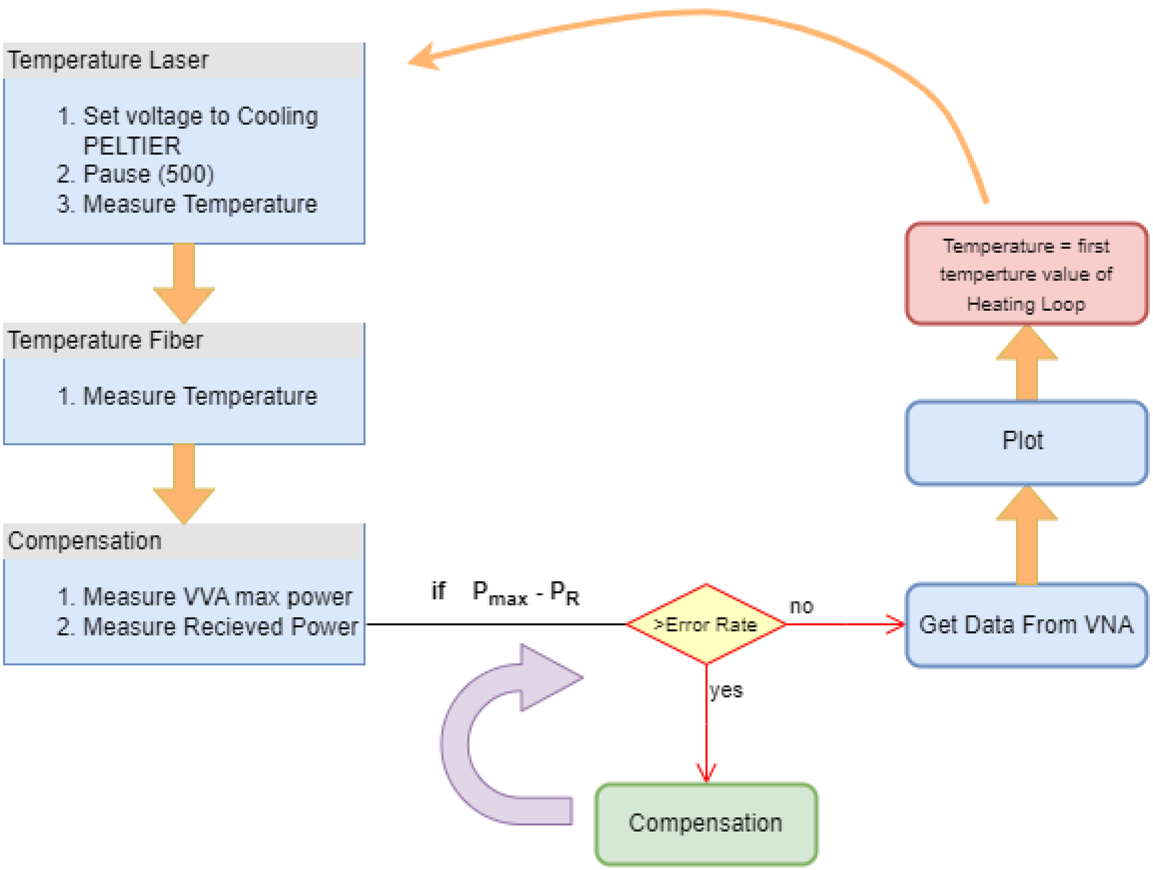

Figure 3.9 Flowchart delineating the cooling subloop process, illustrating voltage adjustments, temperature stabilization, and signal compensation to ensure system stability.

- Peltier Module Cooling:
  The Peltier module voltage is set to the final value reached during the heating phase to start the cooling sub-loop. This maintains stability and continuity in temperature modulation by ensuring a smooth transition and uniformity between the heating and cooling operations.

- Stabilization phase (500 Seconds):
  After cooling starts, there is a 500-second stabilization phase. The technique gives the temperature enough time to attain equilibrium throughout this interval, guaranteeing precise temperature readings and reducing transitory impacts.

- Temperature Monitoring and Measurement: RTD sensors attached to the DAQ device are used to obtain temperature measurements from the laser and optical fiber. Precise temperature measurement is made easier by MATLAB instructions, which also supply vital information for tracking temperature changes during the cooling process. Evaluation of VVA Max Power (Starting Power): Simultaneously, the initial power, or maximum power output of the VVA, is evaluated in order to create a baseline against which compensating changes can be made. Power data from the VVA may be retrieved via MATLAB, allowing precise system performance assessment in cooling scenarios.

- Assessment of Received Power:
  During the cooling phase, the received power is evaluated to assess how well the compensating mechanism is working. By obtaining power data from the photodetector, MATLAB allows one to quantify the signal strength that the receiver receives when the temperature drops.

- Analysis and Adjustment of Compensation:
  The first step in evaluating compensation is to compare the error rate between the measured received power and the maximum VVA power. To maximize signal amplification and preserve stability, MATLAB launches compensating changes if the discrepancy surpasses the predetermined error rate threshold.

- Data Collection and Plot Creation:
  MATLAB collects data from the Vector Network Analyzer (VNA) and creates output graphs that show the cooling system's performance. Plots such as this offer important insights on signal properties and the efficiency of compensatory systems in scenarios where the temperature drops.

- Simulation Ending at the Initial Heating Point:
  The cooling sub-loop ends the simulation by stopping at the first value reached during the heating phase, as opposed to the heating sub-loop's temperature safety check. This makes sure that the data is shown symmetrically, which makes it easier to compare the heating and cooling phases.

By means of careful implementation and adjustment to cooling dynamics, the cooling sub-loop allows for an extensive evaluation of the stability and functionality of the compensation system across a range of temperature scenarios. The compensation technique is better understood and optimized through this iterative process, which ultimately increases the technique's effectiveness in real-world radio astronomy applications.

CHAPTER 4

4.1) Results

The experimental study's findings will be discussed in the upcoming chapter, offering valuable information on how the compensation system functions in different scenarios. The findings are broken down into two primary sections: one that shows the decline in power without compensation, and another that shows the stability of the system and the efficacy of compensating systems with compensation.

- Outcomes without Compensation:

  The system's performance is the main topic of discussion in the first part of the results chapter. The power output drop caused by amplitude changes brought on by external influences, including temperature variations, will be demonstrated through graphical displays. The purpose of this section is to draw attention to the inherent difficulties that radio astronomy systems have in preserving signal stability in the face of changing environmental circumstances.

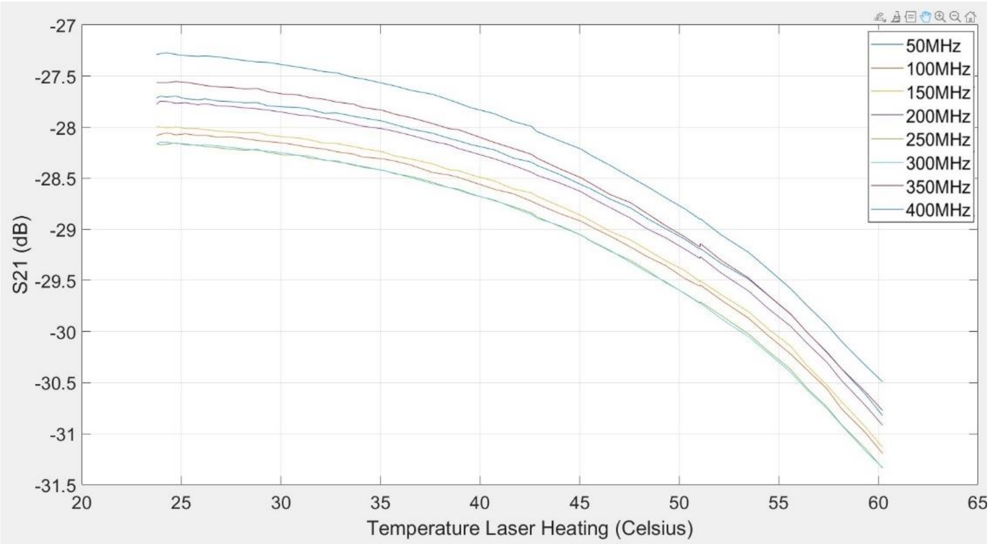

Figure 4.1 (a): Uncompensated amplitude observed in the(pigtailed) laser at 1270nm wavelength.

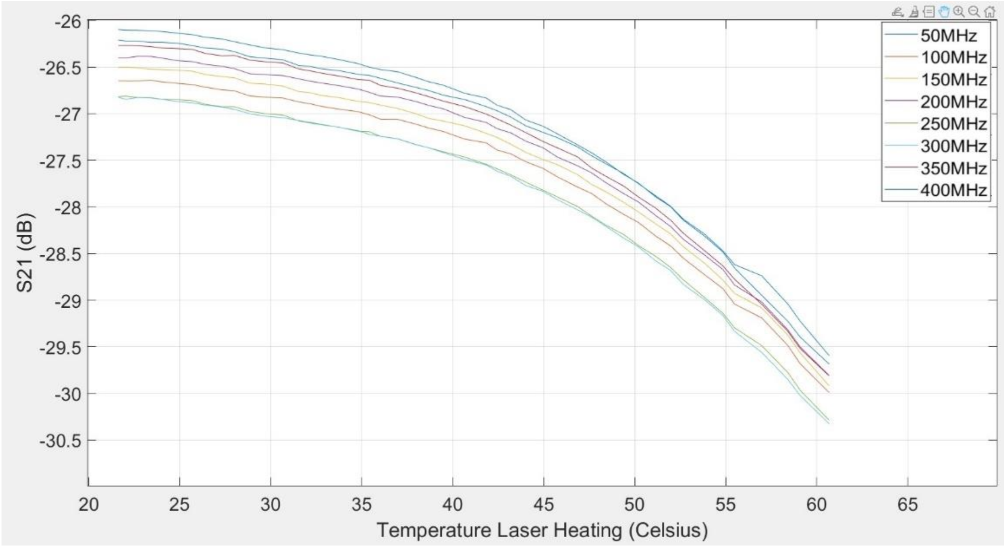

Figure 4.1(b): Uncompensated signal analysis for the Front-End Module (FEM) at 1270nm.

- Outcomes with Compensation:

  This section explores how well the compensation system performs once the results without compensation are presented. The efficiency of compensating techniques in stabilizing the output signal will be shown through comparative analysis and graphic representations. In particular, the figures will show how the compensation system reduces amplitude fluctuations to maintain a steady and dependable output signal in the face of changing environmental circumstances.

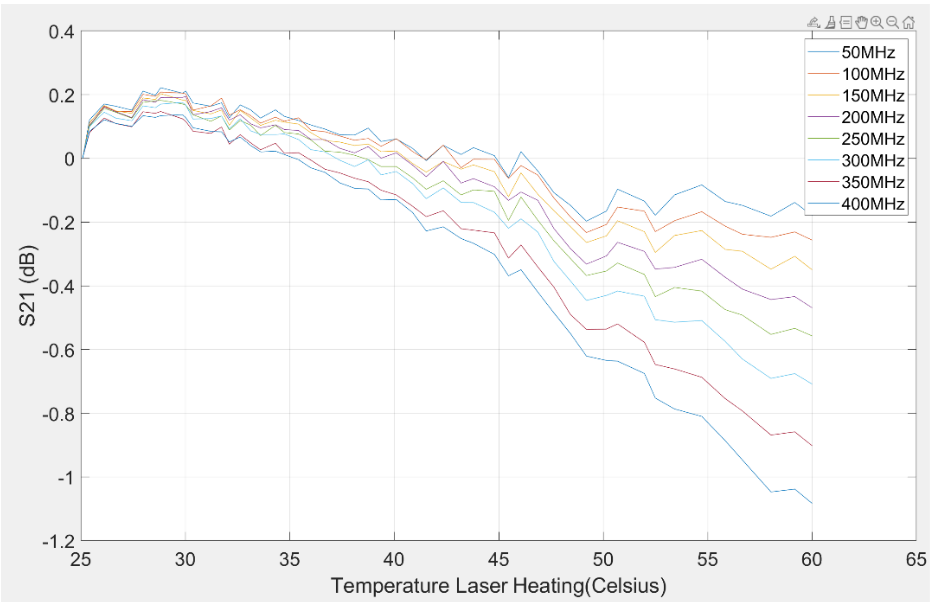

Figure 4.1(c) : Normalized compensated results for the Front-End Module (FEM) at 1270 nm during the heating subloop, demonstrating signal stabilization achieved through compensation techniques.

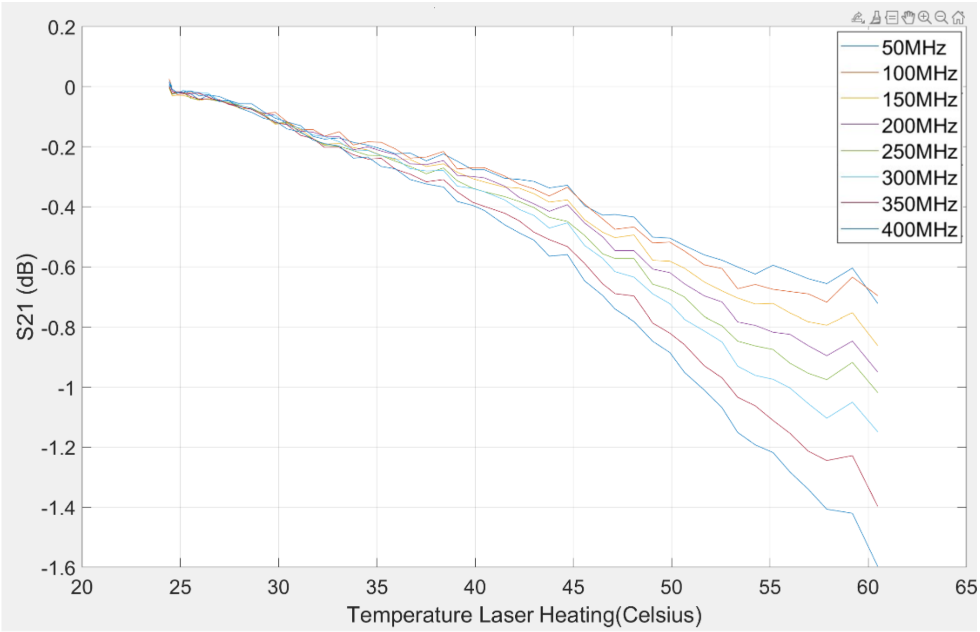

Figure 4.1(d) : Normalized compensated results for the (pigtailed) laser at 1270nm during the heating subloop, showcasing signal stability achieved through compensation.

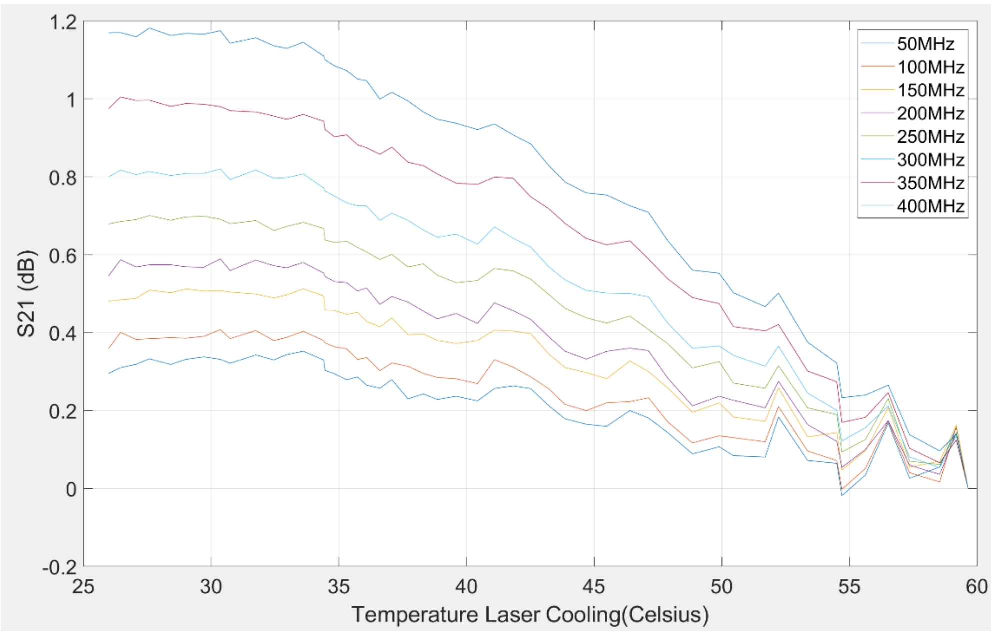

Figure 4.1(e) : Normalized compensated results for the Front-End Module (FEM) at 1270 nm during the cooling subloop, demonstrating signal stabilization achieved through compensation techniques.

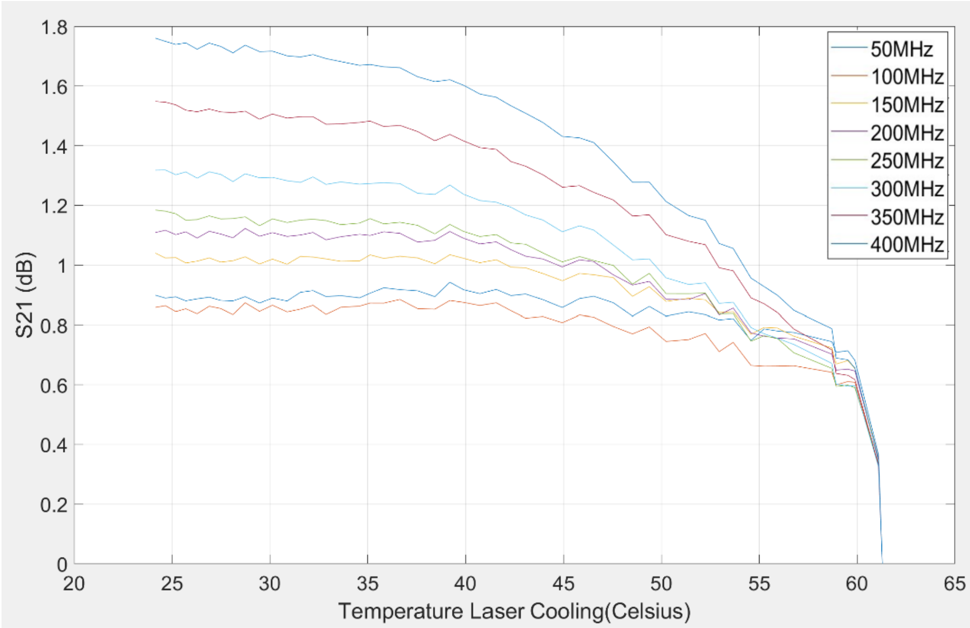

Figure 4.1(f) : Normalized compensated results for the (pigtailed) laser at 1270nm during the cooling subloop, showcasing signal stability achieved through compensation.

Figures illustrating the power production in various conditions will be included in each section. The data displayed in the "without compensation" section will illustrate the observed decrease in power with time, emphasizing the difficulties caused by amplitude swings. On the other hand, the numbers in the "with compensation" section will show how the system can stay constant in terms of power production by using compensation strategies. In this chapter, the performance of the compensation system and its influence on signal stability in radio astronomy applications are intended to be thoroughly understood through the results that are presented. The figures' visual aids will make it easier to understand and analyze the experimental results, which will benefit the development of compensating techniques for radio astronomy equipment.

4.2) Result Comparison

A comparison study between the results obtained with and without compensation will be performed by superimposing the data in a single figure in the upcoming section of the findings chapter. The goal of this approach is to offer a thorough comprehension of how the compensating system affects signal stability. The FEM results are shown in Figure (b), and the pigtailed laser experiment results are shown in Figure (a). The effectiveness of the compensation system at various frequencies will be graphically represented through representation, enabling a comprehensive evaluation of its performance under varied testing situations.

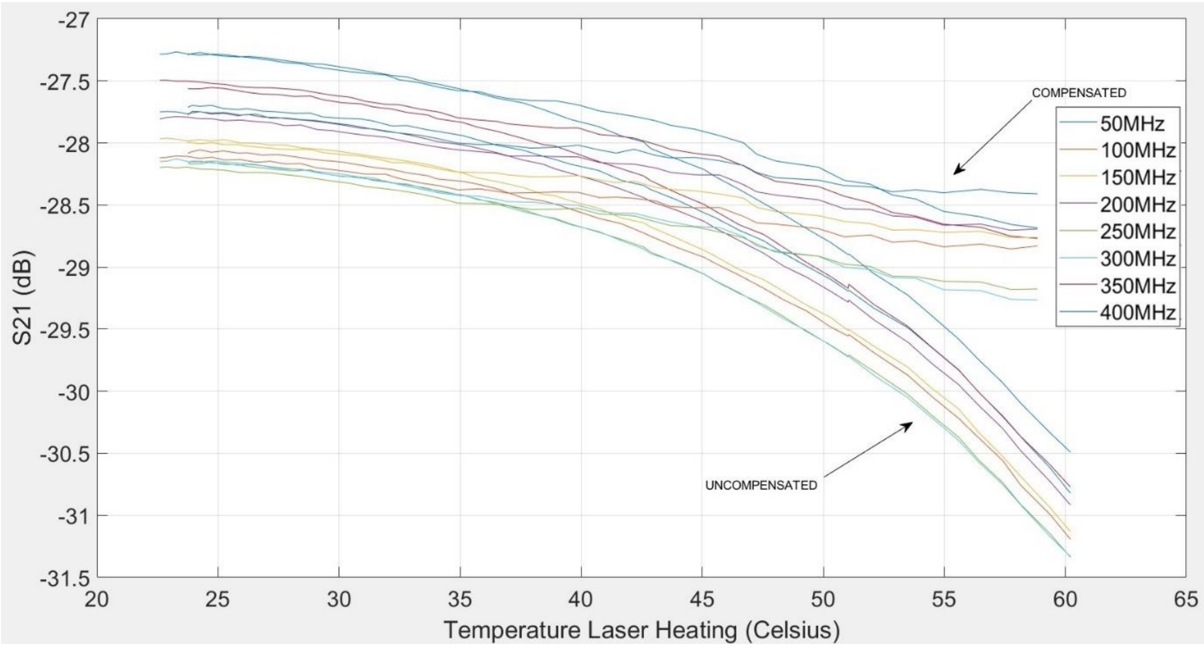

Figure 4.2(a) Comparison between uncompensated and compensated laser output at 1270 nm, demonstrating the effectiveness of the compensation system in stabilizing signal amplitudes.

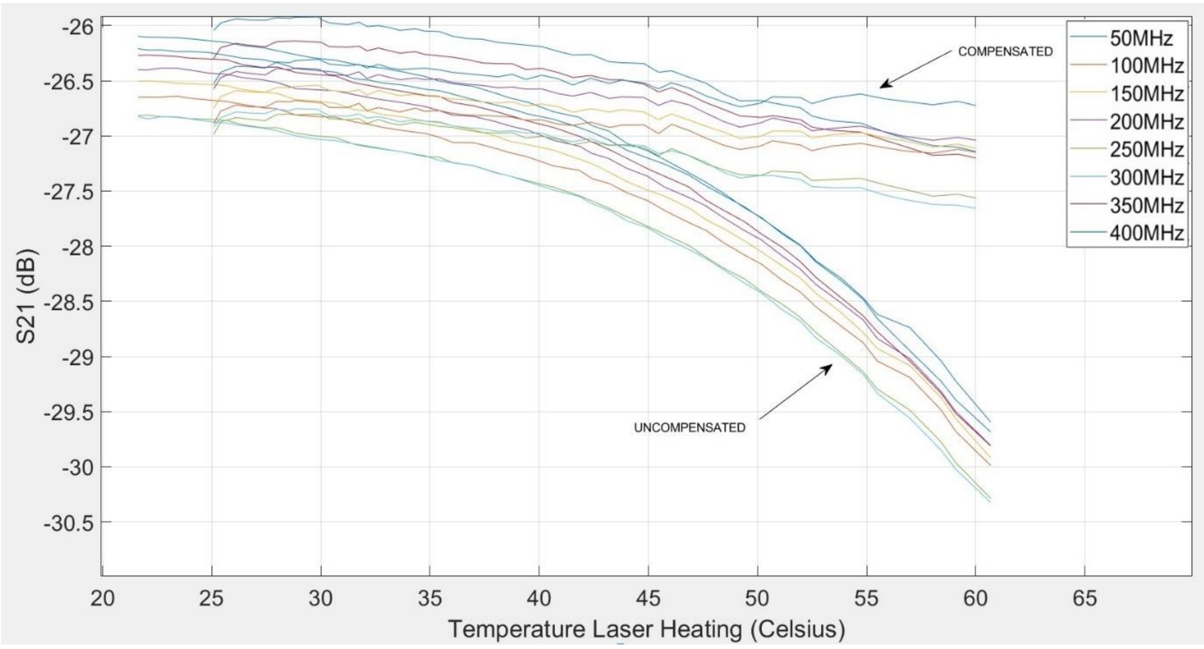

Figure 4.2(b) Comparison of signal stability between uncompensated and compensated Front-End Modules (FEM) at 1270 nm wavelength, demonstrating the efficacy of the compensation system in mitigating amplitude fluctuations.

- Comparative study:

  The power output graphs obtained with and without correction for specific frequencies are superimposed in order to do a comparative study. When the two data sets are compared on a single figure, it is easy to see how differently compensatory strategies affect signal stability. This method allows power production fluctuations under different environmental circumstances to be directly compared.

- Random frequency selection:

  To reflect a wide range of operating conditions, random frequencies will be chosen from the dataset. These frequencies will be deliberately selected to cover both high and low frequency ranges, providing information on how well the compensation system performs in various spectral regions.

- Graphical Representation:

  Different line plots showing power output fluctuations with and without correction will be displayed in the overlapped figures. To encourage clarity and make the comprehension of the data easier, each line plot will have an appropriate title. Furthermore, the axes will bear suitable labels designating the frequency and power levels, so augmenting the readability of the graphical depiction.

- Analysis of Overlapped Figures:

  Important conclusions about how compensation affects signal stability will be derived from a visual examination of the overlapped figures. In particular, areas where compensatory mechanisms efficiently reduce amplitude variations will be pinpointed, demonstrating the system's capacity to sustain steady power production in spite of outside environmental influences.

- Discussion of Results:

  The results pertaining to the overlapping figures will be examined in light of the compensation system's overall effectiveness. The focus will be on clarifying how compensation methods work to stabilize amplitude changes in signals and enhance the accuracy of radio astronomy measurements.

This section attempts to give a thorough evaluation of the compensation system's performance over several frequency bands by comparing the results. In radio astronomy applications, the overlapped figures provide a visual assessment of the system's effectiveness in reducing amplitude fluctuations and guaranteeing signal stability.

CHAPTER 5

5.1) Conclusion

To sum up, this thesis has tackled the critical problem of reducing amplitude variations in radio astronomy systems caused by external factors. Significant improvements in signal output stabilization and measurement reliability in radio astronomy have been made possible by the design and implementation of a complex compensating system.
The thesis started out with a thorough description of the goals of the study, including how to improve a Radio-over-Fiber (RoF) system to monitor and compensate for fluctuations brought on by outside agents and how to implement a compensation system for amplitude fluctuations. The effectiveness of the compensation method has been proven through rigorous experimentation and analysis, providing promising possibilities for improving the performance of radio astronomy instrumentation.
The efficacy of the compensation system has been amply demonstrated by the experimental findings reported in the thesis.

It has been demonstrated by a comparison of power output graphs with and without compensation how well the system reduces amplitude variations at different frequencies, guaranteeing stable and dependable signal transmission in the face of changing environmental conditions.
In addition, the compensation system's viability and adaptability have been demonstrated through the integration of hardware and the application of MATLAB control algorithms. Efficient communication and control have been created by means of rigorous calibration and configuration procedures. This allows for the real-time modification of system parameters and dynamic compensation in response to external stimuli.

Overall, the results of this thesis emphasize how important compensation methods are for dealing with amplitude variations in radio astronomy systems. The compensation method that was created has the potential to significantly advance research in radio astronomy and related fields by boosting measurement reliability and signal stability.
In the future, research and development activities can concentrate on improving the compensation algorithms, enhancing system functionality, and investigating new uses for the compensation system across a range of scientific fields. The suggested compensation plan has the potential to significantly expand radio astronomy

instrumentation and enable ground-breaking discoveries that deepen our understanding of the cosmos, provided that it is implemented with ongoing creativity and cooperation.

5.2) Ongoing Activities

The current work intends to extend the experimental validity to 1330 nm wavelengths. Modifications to the setup, data collecting, analysis, system calibration, and comparison of results acquired at 1270 nm are among the crucial tasks involved in this expansion. Furthermore, additional optimization work will be done on the Voltage Variable Attenuator (VVA) to improve its performance at various wavelengths.

To further improve the efficiency and flexibility of the compensation system, efforts will be made to realize an analog feedback circuit for compensation. Real-time changes to reduce amplitude variations will be possible with this feedback mechanism, which will enhance signal accuracy and stability in radio astronomy applications.

In addition, an investigation for substitute piloting tones that is, frequencies other than the current dithering tone will be carried out. The goal of this study is to find more frequency possibilities that might provide better compatibility with particular system needs or better compensatory capabilities.

The current work aim to improve the compensation system's usefulness and efficacy in radio astronomy applications by validating and optimizing it for a wider range of wavelengths.

CHAPTER 6

6.1) References

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