IDENTIFYING AND REDUCING RADIO FREQUENCY INTERFERENCE BY SPECTRUM ANALYSIS

Introduction

What is a radio telescope?

Static on your radio does not come from out of nowhere. It may be from ground based interference, but some of it is from objects in space emitting natural radio signals. These are essentially natural transmitters. Unlike an optical telescope, a radio telescope is a receiving system designed to watch these signals and identify where these signals are coming from in space. Radio telescopes are used at many different frequencies. The radio telescope at my school is at the frequency of hydrogen, 1430 MHz. This is the most popular frequency for radio astronomy.

A basic radio telescope consists of four major sections: the antenna system, the front end, the back end, and a data logging device. Most radio telescopes at 1430 MHz have a parabolic dish with a 1430 MHz fed horn. Then, either the entire receiver or its first stage is on the dish. The demodulated signal or the Intermediate Frequency (IF) is sent down to the back end. The back end is usually where the signal is amplified and integrated for data logging. The final section of a basic radio telescope is the data logging device. Most amateur radio telescopes will use a Strip Chart Recorder (SCR) or a simple Analog to Digital converter (A/D converter). This is where the signal out of the back end is logged over long periods of time to look for changes in signal strength. An increase in signal strength indicates a rise in temperature to where ever your dish may be pointing. All of the data collected can be put together to make a map of the radio universe and thus you see things in the universe that cannot be seen with an optical telescope.

How I became involved.

I became involved in radio astronomy through my friend Steve. Steve and I had been into electronics, Amateur Radio, and computers for years. We were looking for a technical club at school and so joined the Radio Astronomy club. The reason why I joined was to work on the electronics. Every year the front end is taken off the dish over the summer months when school is out. This year when we put the front end back on the dish it worked fine at first then stopped working. It stopped working after a cable mix-up in the control room. Since I was the only one who knew electronics it was my job to fix the receiver. I worked on it all the time, and we even took it to the National Radio Astronomy Observatory in Green Bank, West Virginia and used all of their good test equipment. This thing was not working anytime soon. But I did rebuild the Operational Amplifier (OP-Amp) board and many other things. And from this I became a believer in radio astronomy. Even though the system was still not working the advisor of the club asked me if I wanted do make a project for the science fair. So I designed a new receiving system for the radio telescope that was an original design.

An electronics background

Ever I could remember my life has been devoted to electronics. I always used to take things apart like old television sets, radios, stereos, car radios, marine two-way rigs, everything. People would always give to me their broken appliances. But eventually I started to build things out of all these parts laying around my basement. I knew how to use tools, and learned to draw and read schematics at age 8, learned how to used transistors when I was 9, and I came into radio when I was 10 or 11 with CB radios. I then became bored with CBs and moved on to amateur radio at age 12.

I was interested in amateur radio mainly because people would build their own equipment and HAM equipment looked so interesting and professional. I finally passed my Novice and Technician theory test in May of '93 and received my license in August of '93 at age 13. I immediately started building my own equipment. I would try building quirky transmitters out of old television and radio parts. I soon became better at this and went to all the HAM swaps. I started collecting military and commercial surplus gear. All the good parts could be found in this kind of surplus. I started building amplifiers, and converting commercial gear to the HAM bands. I even built my own Very High Frequency (VHF) two meter (2m) synthesized receiver.

During 8th grade the shop teacher at my middle school started a new after school project: The solar car. In the solar car project I was in charge of the electronics, and came up with the designs for many other parts of the vehicle. We started in January of '94 where I was in charge of also getting all of the electronics, including the motor, for the car. This is where I learned to get things done because we had a fully operational vehicle by the end of the school year in '94. This was an incredible feat in such a short time.

Our high school radio astronomy club often takes field trips to other radio observatories and, in my sophomore year, we took a field trip to see the impressive Big Ear radio telescope at Ohio State University. While visiting Big Ear I was talking to a physicist who runs an engineering firm in Powell Ohio. After talking to him for a while about all kinds of other radio subjects I was offered an internship at his company. I worked the entire summer for Aeroflex LINTEK as an intern engineer. At LINTEK we build radar systems for military stealth programs; Northrup's B2 program, and do custom RF design. While I was working this past summer I learned huge amounts of theory in RF, digital, and construction techniques. During the day I would build radar systems at work and after work I would work on my receiving system for the radio telescope.

The Idea

After being asked by the radio astronomy club advisor to do a science project I had to think of something original. After thinking it over for a couple weeks I decided to build an entirely new receiving system. The new system was to have a spectrum analyzer and be a superhet design. I couldn't just design and build a spectrum analyzer, there's nothing different about that, I would be reinventing the wheel. So I had to come up with another idea to go with the spectrum analyzer. This idea was to filter out Radio Frequency Interference (RFI) by manipulating the demodulated signal off the output of the spectrum analyzer (the video signal) by comparing that to the sweep oscillator's output within the sweeping Local Oscillator (LO) circuit.

The Problem

When a radio telescope is placed within a city there is a huge amount of RFI to be dealt with. You can't go around to every cellular phone tower and complain to the FCC about a messy transmitter. Or write the garage door company a complaint about their remote openers because of their spurious emissions. It is up to the engineer to design a receiving system that can eliminate this RFI. This is where my idea comes into play.

Hypothesis

I hypothesize that RFI can be identified and eliminated by the design and fabrication of a new receiving system for our radio telescope. My system would include a downconvertor, spectrum analyzer, the Frequency vs. amplitude plot separator, and the Filter Chassis. RFI could be eliminated after the comparison of many scans worth of data over a long period of time.

Procedure

The overall design for the new receiver was that of a spectrum analyzer. Using a video signal the system would be able to manipulate the data going into the data acquisition devices. This system was built in seven different sections. These sections are: the Downconverter, IF Chassis, Filter Chassis, Frequency vs. amplitude plot separator, Power Supply, Cabling System, and the placing together of the entire system. Each section was researched, designed, fabricated, redesigned, and field tested.

The Downconverter

Problem

The problem here was that the previous receiver was a direct conversion type (fig 1) and I needed a superheterodyne in order to build a spectrum analyzer. The old receiver had an interesting design. The entire receiver was mounted at the focus of an 18 foot parabolic dish. From there the video signal was fed into the control room to a back end. The RF would come in through an isolator, into a 27db gain LNA, then through a bandpass filter with center frequency at 1415MHz and band width of 30MHz. Next it went into another 27db gain LNA, through a 3db attenuator, and then through a last 27db gain LNA. This went to a bandpass filter with center frequency of 1415 MHz and a bandwidth of 30 MHz, then to a square law detector. The square law detector's output went to a video amplifier board with a gain of x200. On top of the RFI problems encountered there were also numerous design flaws that were causing problems. There were problems with feedback from the tremendous gain of the three LNAs at the same frequency. This would cause the receiver to oscillate and give large but false signal strength readings. There were also problems with saturation of the third LNA for the same reason.

Hypothesis

A new receiver was needed. This was because of the problems with the old direct conversion receiver and because a superhet was needed for spectrum analysis. The 1430 MHz RF is too high of frequency for a 150 foot cable run of RG-9913, but I could not place the entire receiver up on the roof and run the video signal down to the control room. So I decided to split the superhet receiver into two different sections. The section on the roof is called the downconverter. The downconverter converts the 1430 MHz RF signal into an IF frequency of 75 MHz which retains all the characteristics of the 1430 MHz signal except at a lower frequency and can be sent down to the control room without the loss of signal.

Designs, problems, and design changes

The first design incorporated a triple conversion superhet, where the first and second stages were in the downconverter up on the roof near the dish. The first and second IF's were tuned by UHF VCO's salvaged from old commercial radios being swept by a function generator set to output a low frequency sine wave from the control room. The IF was then mixed with a crystal oscillator then to a ceramic filter and to a detector. The detector's output was then amplified and fed into an oscilloscope on the y axis input with the sweep coming in on the x axis input. The rest of the system worked off this video signal.

After designing this the current receiver failed yet again and it was decided to purchase another receiver. This system was a superhet and had a downconverter that was to be placed by the dish, the same as my previous design. So the old downconverter design was scratched and my receiver's design was changed to work with this downconverter. This system consisted of a feed horn at 1475 MHz according to the Smith Chart printouts (fig 3) and the VSWR printout (fig 4) from the Wiltron Network analyzer at work. The feed horn went into an LNA with a gain of 27db at 1475 MHz and a bandwidth of about 1000MHz according to the frequency vs. amplitude plots off the network analyzer (fig 5). The LNA feeds into a downconvertor. Inside the downconverter is a bandpass filter with center frequency of 1475 MHz and a bandwidth of 25 MHz. This feeds into a mixer whose LO is a PLL frequency synthesizer set to 1400 MHz. The output of the mixer goes to a 75 MHz low pass filter which gives a 75 MHz and lower IF. This feeds into an IF amp. Then the IF exits the downconverter box and is fed into another IF amp with a gain of 18db. The output of this IF amp feeds out of the hermetically sealed enclosure to a 150 foot cable run of RG-9913 into the control room and from there to the back end. Inside the back end the 75 MHz if is fed into another IF amp then to a detector circuit. The detector circuit's output is then amplified through numerous video amps and integration amplifiers. Then the integrated video signal is outputted to some sort of data acquisition unit.

This system was first installed and tested in January of '96. The system failed and was sent back. The problem found was that the 1475MHz input to the downconverter module's connector had a piece of wire stuck in it shorting the input. This was a quality problem on the manufacturer's part by using a cable TV F connector instead of a good 50 ohm connector. The temporary enclosures were not very waterproof to be on the roof all day and there were water problems.

Taking all these problems into consideration and knowing that we now had a downconvertor and a new one no longer needed to be fabricated, research was done into finding a good way to construct a waterproof enclosure. Two military surplus pieces of equipment were purchased at the Dayton Hamvention '96. One of them was some sort of aircraft test computer and the other was a signal generator. I wanted to keep the signal generator so I chose the test computer's case to be used to house the downconverter. The test computer had never been opened so it still had all of its military connectors and good parts inside of it.

I used the military connector off of the test computer for power on the downconverter box (test computer box). I attached the military connector and two N female bulkheads onto the box and water sealed them. Next I wired a bus off the military connector and wired a test point panel to the bus I salvaged off of the test computer's insides. I was now ready to put the modules of the system inside the box. I lined up the modules so that there would be the shortest cable run possible for the 1475 MHz signal (which was this downconverter's center frequency) which has the highest loss and longer runs for the 75 MHz IF which has the lowest loss. I used old pieces of Semi-rigid 402 taken out of garbage cans at work for the 1475MHz signals. Then I used RG58 for the 75MHz IF. I replaced the cheap F connector on the downconverter module with a gold plated SMA female bulkhead for Semi-rigid 402. A thermocouple was also installed in the box to monitor temperature. After lining up the mounting holes on everything and putting it together it worked with only one hang up.

The problem was there was no signal coming out of the second IF amplifier. I believed the problem to be at first the saturation of the second IF amp. But further analysis showed that there was also no signal coming from the 1475 MHz LNA. The problem turned out to be the +12 volt line wasn't distributing power to all modules that needed +12 volts. These were the 1475MHz LNA and the second IF amp.

Bench test results

A log periodic antenna was attached to the 1475 MHz input on the hermetically sealed downconverter box and when the lights were turned on and off the output varied by about 1 volt from the back end. And the IF output when hooked up to my spectrum analyzer was stronger than before peaking past 0 dbm (fig 10).

Field test results

Scans were made using the downconverter and the back end supplied with this system. The system proved to be extremely sensitive. Large variations in signal strength between 6v and 7.38v were indicated by one of our first scans (fig 6). This proves that the downconverter was very sensitive when used with the bare bones back end.

Current Design

The current design isn't much different from the manufacturer's intended design. The components are housed in a military surplus hermetically sealed case. The 1475 MHz RF enters through an N bulk head connector that feeds into semi rigid 402. The 402 feeds into an N connector that goes into the 27 db gain LNA. The output of the LNA goes into the downconverter module through a gold plated SMA female bulkhead that I replaced the old F connector with. There are no more modifications within the downconverter module which feeds out into a BNC female connector. Silver plated BNC male to male cable connects the output of the downconverter module to the second IF amplifier module. Then there's another BNC male connector hooked up to the output the IF amp module that goes over to a silver plated N female bulkhead where the 75 MHz IF exits the case.

Power enters the hermetically sealed case through a 9 pin military bulkhead connector. Each pin of the connector is soldered to a wiring bus then from the wiring bus to a test point panel within the case. There is a thermocouple set up as a voltage divider with a 1K Ohm resistor on the wiring bus that is outputted back through the military connector.

The IF Chassis

Problem

I needed a spectrum analyzer. The spectrum analyzer had to be the back end of the receiver. This is because the 1475 MHz is too high of a frequency to bring into the control room with 150 feet of 9913 cable. The spectrum analyzer had to sweep the IF frequencies and be sensitive enough to give a high video signal output but not be too sensitive as to saturate its RF components and thus render itself useless.

Hypothesis

In order to have an accurate video signal for the rest of my system the spectrum analyzer must sweep frequencies very quickly. It must be stable and sensitive, but not too sensitive. And the spectrum analyzer must have both a video output and a sweep oscillator output. This is because the sweep oscillator controls what frequency the LO is on in the spectrum analyzer and is thus a voltage that is a function of frequency. This is how the rest of the system can determine what frequency it is on.

Design, problems, and design changes

The original design incorporated two commercial VCOs to be swept by a function generator set to output a low frequency sign wave. The IF output of this front end went down into the control room where it was mixed once more with a crystal oscillator then to the long wave receiver, and from there to two video amplifier (Fig 2).

Redesign started immediately after the purchase of the new downconverter modules to make my spectrum analyzer compatible. The second design was made up for the spectrum analyzer sweeping in frequency the 75MHz IF. Research again took place using the <u>Secrets of RF Circuit Design</u>, The <u>ARRL Handbooks</u>, and in the <u>Mini Circuits RF IF</u> designer's guide.

The second design incorporated a AN/TRM-3 sweep generator found at the swap to replace the original design of the two commercial VCO's and function generator. This design incorporated one frequency mixer and a long wave receiver. The 75 MHz IF would be fed into the mixer, the mixer was injected by an LO signal from the TRM-3 and the output of the mixer fed into the long wave receiver which had a frequency range of 230 kHz to 450 kHz. The receiver was then modified so that the detector was DC coupled to make signal strength measurements instead of AC coupled which is used for listening to audio. If a circuit is AC coupled only waves that are always changing in time will pass like sine waves and video signals but not straight DC signals because they do not vary over time. When a circuit is DC coupled everything will pass, even straight DC voltages. This was then amplified with two video amplifiers. All of this was mounted on a slab of aluminum. This system (fig 7) would give a wider frequency range that can be listened to because there is only the addition of one stage at a maximum of 450 kHz. So the received frequency would be 450 kHz + TRM-3 frequency + 1400 MHz. Because this system would allow me to listen to lower frequencies off the IF it would work perfectly.

The third design was an adaptation of the second. This design also incorporated a rack mounted enclosure for mounting all equipment neatly in a standard 19 inch rack that had to be 8 inches deep to fit the long wave receiver and had to be made of 10 gauge aluminum front panel and 32 gauge for the rest of the case. The first IF (75MHz IF) would come down into the control room into the IF chassis through a N bulkhead. There it would go through a Mini Circuits ZFAT-51020 programmable attenuator which had a very flat bandwidth of 1000 MHz on each different attenuation setting (fig 11-15). A problem was encountered with the programmable attenuator. While testing it on the Wiltron Network Analyzer at work the device stopped completely and there was no signal coming out of its output. The programmable attenuator was sent back to Mini Circuits and they found that one of the Transistor Transistor Logic (TTL) lines was fused to the chip (fig 21). They said this was because of high voltage (static, power surge, etc.) or from having the TTLs biased without power flowing to the device. But none of these had happened and I was grounded to the network analyzer while testing so it must have been a power surge or a quality problem. A new attenuator was purchased and the old one was sent back.

From the programmable attenuator the signal goes into a Mini Circuits double balanced mixer ZFM-2 that has an LO/RF frequency range of 1 to 1000 MHz and an IF frequency range of DC to 1000 MHz (fig 16). The TRM-3 sweep generator's RF output is fed into a Mini Circuits ZFL-1000LN LNA that has a gain of 20db and a bandwidth of 1000 MHz (fig 17). The mixer's saturation level is 7dbm but if you go too far below 7 dbm the RF saturation level decreases from 1 dbm. The sweep generator's highest stable output is 0dbm. There is an attenuator built into the sweep generator which is set to 13db.

Thus the output of the sweep generator is -13db. When the LO enters the IF chassis it is amplified by 20db by the Mini Circuits LNA to give an output of 7dbm which is within the mixer's threshold of top performance. The output of the mixer fed into an old AM long wave receiver which covered 230 kHz to 450 kHz. This goes to a video amp and then out to the rest of the system. Another problem had arisen, the power supply couldn't carry the long wave receiver. The power supply's 24 volt output was only rated for 1A, and the Long Wave Receiver needed more than that. Also, the receiver was very temperamental in its operation. Sometimes it worked sometimes it didn't. This was because of loose wires. The receiver was also not a very accurate instrument for measurement so it was replaced in the fourth design.

The fourth design was a re-engineering of the second IF that was the long wave receiver. In the long wave receiver's place there was a ceramic filter with a center frequency of 455KHz and a bandwidth of 3 kHz. Then a square law detector was hooked up to the output of the ceramic filter (fig 8). The problem with this was that it produced cosine waves which are 180° out of phase from sine waves but at the same frequency. My cosine waves were being produced within the mixer. A frequency mixer has several different frequencies coming out of it at once. These include the RF-LO, RF+LO, RF, and LO. In my circuit I wanted the RF-LO. I achieved this by filtering out all other frequencies with the ceramic filter. But whenever the RF was less than the LO there would be a "negative" frequency, or a cosine wave. When the LO was set to 100MHz and the RF at 100.455 the output of the mixer was 100.455 MHz-100 MHz = 455 kHz sine wave which was the desired signal that showed up on the output of the square law detector. But when the RF was set to 99.505 and the LO was at 100MHz then 99.505MHz-100MHz=-455KHz, or a 455KHz cosine wave which is undesired and also showed up on the output of the square law detector. From this there would be 2 spikes on the spectrum display on the sweep generator instead of one when an IF signal at a fixed frequency was injected from my signal generator (fig 20). This would also not work.

The fifth design was the addition one more stage to replace the ceramic filter. On the output of the Mini Circuits mixer there was an IF board added that was salvaged out of an old Ensign VHF marine radio from the early 70's late 60's (fig 18). I made numerous modifications to this board. I isolated its front end and cut the circuit board foil around it with a razor blade to take it out of the circuit. Then I hooked the input of its 20MHz crystal filter to a gold plated SMA female bulkhead. The output of the Mini Circuits mixer fed into there. The second IF is made of an LNA on the output of the crystal filter that feeds into another mixer. This mixer's LO is a crystal oscillator at 20.455MHz. Thus mixing to 20MHz-20.455MHz=-455KHz. There's 455KHz filter on the output of that mixer which goes to the third IF amp and then to a relay which selects either the square law detector I placed onto the board or its original narrow band FM phase discriminator. On the output of the square law detector is a video amp with a gain of x1000. This was calculated by using the gain formula for non-inverting op-amp circuit, gain=1+(R1/R2). The relay that switches the third IF also switches the input of the audio amplifier on the IF board between the HP square law detector and the phase discriminator so that signals can also be listened to in case we intercept narrow band FM transmissions that may be harmonics of commercial transmitters.

Bench test results

I attached my HP-510 signal generator to the IF input of the IF chassis. I set the signal generator to 75 MHz and the TRM-3 sweep generator to 75 MHz - 20 MHz - 455 kHz = 54.505 MHz. I set the sweep to 20% deviation and I picked up only one spike from the signal generator (fig 19). This proves that the cosine wave problem had been eliminated with the addition of one more stage.

Current design

The current design (fig 22) is much more complicated than the first. When the 75 MHz IF enters the IF chassis it goes straight into the Mini Circuits ZFAT-51020 programmable attenuator. The programmable attenuator's output is fed into the Mini Circuits ZFM-2 double balanced mixer. The mixer is injected with an LO signal from the AN/TRM-3 after being amplified by the Mini Circuits ZFL-1000LN. The IF output of the mixer is fed into the Ensign VHF marine radio board that makes up the second and third IF stages. The mixer's output goes into a 20 MHz crystal filter. The filter's output feeds into an IF amp. The IF amp feeds into another mixer that is injected with a 20.455 MHz crystal oscillator. The output of this mixer is the third stage that has a narrow band 455 kHz filter that feeds into an other IF amp. The output of this IF amp feeds into a relay which selects between the phase discriminator on the VHF board and the HP square law detector I installed with a gold plated SMA female bulkhead connector. The demodulated output of the square law detector feeds into a video amplifier board with a gain of x1000. The gain and offset controls for the video amplifier board are on the front panel in two ten turn precision potentiometers. The 100 K Ohm is set up as a voltage divider between -15 and +15 volts for the offset control and is biasing the feedback resistor on the second op-amp of the video amplifier board. The other potentiometer is valued at 10 K Ohm. This is the feedback resistor for the first op amp on the video amplifier board. This varies the gain from 1 to 10 on the first op-amp, and since the second is fixed at x100 the gain varies from x100 to x1000. The output of the video amplifier goes to a female BNC connector on the back of the chassis next to the IF input and LO input connectors. The video output also goes over to the phase discriminator and square law detector relay where it can be switched between the phase discriminator's output to the audio amplifier built into the marine VHF board.

There are also three switches with red Light Emitting Diodes (LEDs) above them. These are for the 5 volt bias voltages for the programmable attenuator. The programmable attenuator has 4.7 K Ohm resistors in series with the three TTL switches to keep the bias current down.

The power enters the chassis through a 6 pin female Jones bulkhead connector. This is the standard power pin out for all chassis. +5, +12, +15, -15, and +24 volts enters here. All voltages except for the +24 volt line are turned on by a four way switch on the front panel and a green LED in series with a 1 K Ohm resistor to +12 volts indicates power. The +24 is switched on by a relay controlled by +12 volt line.

There is a volume and squelch control for the VHF marine radio on the front panel that controls the volume for the audio amplifier and the squelch for the phase discriminator only. The control turns off the audio amplifier in full counterclockwise position. The switch to the left of the volume and squelch control turns the power for the phase discriminator and square law detector relay. When turned on, the relay selects the third IF to the phase discriminator and the input of the audio amplifier to the phase discriminator's output. When turned off it selects the third IF to the square law detector and the audio amplifier input to the output of the video amplifier board.

Filter Chassis

Problem

Now that I had a spectrum analyzer I needed a way to eliminate RFI. The device cannot eliminate RFI at the RF or IF level because of the high expense it would take to do this. Also, since the RFI will be seen on the spectrum analyzer, I did not need expensive adjustable helical filters or tuned cavities. This device must be able to eliminate narrow band RFI that shows up on the spectrum display to keep it from affecting the video signal's overall average.

Hypothesis

To satisfy the above requirements I designed the Filter Chassis. Since IF and RF filtering measures cannot be taken to eliminate RFI the Filter Chassis must utilize the video and sweep voltage to perform this task.

Designs, problems, solutions, and design changes

The Filter Chassis utilizes window comparators that compare reference voltages to the sweep voltage coming out of the TRM-3 sweep generator. The reference voltage is a sine wave which is a function of frequency. When the sweep voltage meets or exceeds a reference voltage the video signal is turned off and when the sweep voltage meets or exceeds another reference voltage the video signal is turned back on thus taking an RFI spike occurring at that frequency out of the video signal average.

The first problem with the Filter Chassis was the decade counter board (fig 23). Because I was desperate for Integrated Circuit (IC) sockets this summer I used old wire wrap sockets. The problem that occurred was in the hooks I made on my wires attached to the sockets. I used hooks because I couldn't bend the pins over to solder. These hooks were close together and they shorted. So I replaced all the old wire wrap sockets with regular ones to solve the problem.

The next problem was with the window comparators. On the output of the comparator circuits there was a strange wave form, not a high-low signal that was expected. But this wave form was in sync with the sweep voltage (fig 24). When I changed the reference voltages the phase of the signal also changed because the reference voltages would trigger the signal according to the 25 Hz sweep voltage.

The window comparator circuits were powered by +12 volts at the time and the ground on each LM339 comparator chip went to ground. I changed the VCC voltage from +12 to +15 volts and I placed -15 volts at the ground of the two LM339 comparator chips. Now the signal was a high-low signal but the high was at 0 volts and the low was at -15 volts in sync with the sweep voltage (fig 25). Because of this the polarity on the IN914 diodes had to be switched around so that negative signals could pass. And because the trigger signals were negative coming out of the comparator circuits they would not be usable for TTL input to the 7404 hex inverter chip. I had to add inverting buffer amplifiers to the output of each comparator circuit. These inverted the signal so that the low is now +15 volts and the high is 0 volts (fig 26).

Next I had to run this signal off of each inverting buffer amplifier into an inverter on the 7404 hex inverter in order to give the proper signal to short the video. This is because there are four filters which translates to four comparators. Each comparator is -15 volts when the sweep voltage is not between the two reference voltages and 0 volts when it is. When the sweep voltage is between the two reference voltages the video signal is to be shorted out and thus that portion is taken out of the video signal's average during every cycle of the sweep voltage. The output of each comparator is inverted by the inverting buffer amplifiers and then the low is +15 volts and high is 0 volts. The problem here was that the signal should not be shorted when the voltage is +15, it needed to be shorted when the voltage is 0. So that is why there is a 7404 hex inverter in the circuit. This chip inverts signals at TTL voltages, +5 volts high to 0 volts low, and 0 volts to +5 volts. So I ran the +15 volts trigger into four out of six inverters on the IC. The outputs were +5 volts for high and 0 volts for low. This was perfect.

The 7404 hex inverter started to overheat because the input +15 input voltages were too high for an IC designed for +5 input voltage. So I had to build voltage dividers to put on the output of each inverting buffer amplifier. I used the voltage divider formula: $V_o = V_{in} \times (R1 / (R1 + R2))$. Using a 47 K Ohm resistor as a constant resistance as R1 I solved for R2 and came up with 47 K Ohm for a voltage divider that divides the +15 volts into +7.5 volts which is high for a TTL signal but I wanted it this way in case the 7404 hex inverters drew the voltage down. The formula was: 15 volts × (47 K Ohm / (47 K Ohm + 47 K Ohm)) = 7.5 volts.

When testing the output of each hex inverter there was nothing. Then the input of each hex inverter was checked. I found that a 1.75 volt DC signal was coming out of the input pin of each hex inverter. This signal offset the output of the voltage dividers so that they were not turning the hex inverters over (fig 27). This was from their internal inverting circuitry. So I had to find a way to pull down that 1.75 volts without changing the voltage dividers. I decided to use a diode whose polarities are such that the anode goes to the output of each inverting buffer amplifier so that when the inverters output a 0 volt signal (when they go high), the 1.75 volt signal off the input of each hex inverter will drain back into the inverting buffer amplifiers and short itself out (fig 28). This proved effective and the hex inverters were functioning.

The next step was to replace the transistor video switching circuit that was from the original design with a better video switch. The idea was to short the video because all I had to do was switch it on and off, high and low. So I couldn't just short the video- I had to buffer it first. What I did was run the video through a buffer amplifier and then to a 47 K Ohm resistor. Off the resistor was a NPN transistor's collector. The emitter went to ground and the base was hooked to a 22 K Ohm resistor after optimum bias current was calculated for that transistor to ground using Ohm's law $V = I \times R$. The bias current turned out to be $I = V / R = 5$ volts / 22 K Ohm = $2.27 \times 10E\text{-}4$ amps. The collector of this transistor which is connected to the 47 K Ohm resistor goes in to the second buffer amplifier and outputs the filtered video to the rest of the system. Thus when the transistor is biased the video is shorted out on the output of that first buffer amplifier. This video signal could be +15 volts at maximum so the maximum current that first buffer amplifier must be able to handle is $I = 15$ volts / 47 K Ohm = $3.19 \times 10E\text{-}4$ amps, which is well within operating specs of that particular IC.

Another problem that occurred was that the video was being switched on and off at the opposite time it was designed to be. This was because the output of each hex inverter connected to each inverting buffer amplifier was tied together. Then this signal was inputted into another hex inverter and then the output of that hex inverter went to switch the video signal on and off. This would not work so I took the extra hex inverter out of the circuit and replaced it with a jumper directly from the 22 K Ohm bias resistor to the tied-together hex inverter outputs of each individual filter.

Bench test results

After all of these problems were solved the Filter Chassis was tested on the bench and checked out perfectly. Since I didn't have a video signal available from the receiver yet I used the +5 volt line instead. When compared to the 25 Hz sweep voltage off my function generator the +5 volt signal coming out of the Filter Chassis switched perfectly (fig 29). This proved the Filter Chassis to be operational.

Current Design

The current design incorporates all of the design changes from above (fig 30). Power comes in through the system's standard 6 pin female bulkhead Jones connector on the back panel of the rack mount enclosure. +15, -15, and +5 volts are switched using a four way switch on the front panel with one pole left for spare. A green LED acts as a power indicator and is coupled in series with a 1 K Ohm resistor to the +15 volts side of the four way switch. The power is then distributed to each of the ten turn 10 K Ohm reference voltage potentiometers and to all of the boards. There are two potentiometers per filter. One of them sets the start voltage and the other the stop voltage for however long the video signal is to be shorted out. There is also a switch that switches sweep voltage to each comparator circuit in order to turn on and off the filters. The other switch is to turn on integration on each filter.

The filter board itself contains four filter circuits. On each filter circuit there is a window comparator circuit using half of an LM339 comparator IC. The window comparator is made up of two high and low comparators combined together with diodes where the high signal is 0 volts and the low signal is -15volts. Where these diodes meet is fed into an inverting buffer amplifier circuit taking up ¼ of an LM2902 op-amp IC where the high signal is 0 volts and the low signal is now +15 volts. This is fed into a voltage divider which drops the +15 volts down to +7.5 volts that goes into a hex inverter which takes up 1/6 of the 7404 hex inverter IC. Since the 7404 leaks 1.75 volts out of the inputs of its hex inverters a diode was added in each voltage divider to feed that 1.75 volts back into the inverting buffer amplifiers to short it out. The outputs of each of the four hex inverters goes to a decade counter board that divides the TTL signal by ten and drives the red gate LED's on the front panel that indicate the filters triggering. The TTL signal is divided by ten so that the action of the TTL is noticeable and not flashing too fast. The outputs of each of the four used hex inverters are also tied together and fed into the 22 K Ohm bias resistor that biases the shorting transistor in the video switching circuit. In the video switching circuit the video signal is passed into a buffer amplifier, through a 47 K Ohm resistor, and into another buffer amplifier that are both on an LM358 op-amp. On the input of the second buffer amplifier the collector of an NPN transistor is connected. When biased by the 7404 hex inverter IC the transistor shorts the video to ground and thus turns off the video signal to the rest of the system taking a dirty signal out of the average.

Frequency vs. amplitude plot separator

Problem

Now that I had a way to perform spectrum analysis at 1475 MHz and I was able to filter out unwanted RFI picked up by the spectrum analyzer I needed a way to collect data off the spectrum analyzer. On a radio telescope data is collected over long periods of time and it's hard to collect data off of a spectrum analyzer that is sweeping back and forth in the frequencies 25 times per second. And another problem is that RFI can occur at any given moment, whether it be at 4:30 am or at mid-day.

Hypothesis

The Frequency vs. amplitude plot separator was designed to use the video and the sweep voltage to split the bandpass (the frequencies that are being swept by the spectrum analyzer) into four channels. In each of these channels the strongest signal's frequency and amplitude will be outputted as a function of voltage.

Designs, problems, solutions, and design changes

The first design for the Frequency vs. amplitude plot separator used many different aspects of the first design of the Filter Chassis (fig 31). The sweep voltage would go into a comparator circuit. The two reference voltages on each of the four channels were set to ¼ of the sweep voltage sine wave, thus dividing up the bandpass into four channels. Because the comparator circuits were identical to the first design of the Filter Chassis they feed directly into a bias resistor and into a hex inverter. The transistor being biased would short out a peak detector integration capacitor when the sweep voltage was not within the two reference voltages, or in other terms when the spectrum analyzer is not within that channel's designated bandpass. The peak detector would output the peak of the video signal when it was not shorted out by the transistor. The output went out to a data acquisition device.

The hex inverter would invert the signal so that when the output of the comparator circuit was low the output of the hex inverter was high. This would bias another transistor which would send the video signal into a buffer amplifier. The buffer amplifier's output was integrated with a capacitor and sent into a comparator. The comparator would compare the average video signal for that bandpass obtained from the integration capacitor to the video signal that was not integrated. Whenever the non-integrated video would exceed the integrated video the comparator would output a high signal and bias a transistor that would pass sweep voltage out into an integration capacitor and out to a data acquisition device. This would output the frequency of the strongest signal within that bandpass.

This circuit would not work at all because of the problems found when redesigning the Filter Chassis. So an entirely new board had to be designed (fig 32). In this circuit +15 and -15 volts were powering all the op-amps and comparators instead of +12 volts and ground. This gave a wider dynamic range in dealing with the video and sweep voltage and this was also needed to get the LM339 comparator IC's to function. The diodes in the window comparator circuits were switched around to allow negative voltages to pass instead of positive. Since the output of the window comparator circuits was -15 volts low and 0 volt high, inverting buffer amplifiers were put on the output of each window comparator circuit for each of the four channels. A voltage divider (the same as the one used in the Filter Chassis on the output of its inverting buffer amplifiers) was used before the input of the hex inverters in each circuit. Diodes were also installed to short out the 1.75 volt leakage voltage on the input of each hex inverter to the output of each inverting buffer amplifier to short the leakage voltage. The output of the hex inverters went to shorting out the peak detector's integration capacitors. Then the output of the peak detector went through a diode and a .33 UF integration capacitor to ground and then to a data acquisition unit giving the amplitude of the strongest signal within the set bandpass.

The output of the voltage dividers off of the inverting buffer amplifiers also went to biasing shorting transistors whose collectors short the video off of a 1 K Ohm resistor on the output of a buffer amplifier where the video is first fed into ground. Off of the collector of each shorting transistor is a diode that feeds into an integration circuit with a .22 UF capacitor to ground. From there the signal goes into another buffer amplifier and into a comparator on an LM339 comparator IC as a reference voltage. This is compared to the non-integrated video signal. The output of the comparator goes into an inverting buffer amplifier on an LM2902. The output of this biases an other NPN shorting transistor. The sweep voltage is fed into a buffer amplifier and then through a 47 K Ohm resistor and to the collector of that shorting transistor. Off the collector the signal goes through a diode and into an integration circuit of a

.22 UF capacitor to ground. This feeds into another buffer amplifier whose output goes to a data acquisition unit giving the frequency of the strongest signal within the set bandpass.

One of the problems with this peak detecting circuit design was in finding the values for the integration capacitors. Since exact input impedances were not known for the different op-amps, it was strictly trial and error.

A problem did occur with the comparator in the frequency circuit. The integration of the video in this circuit was on the input of the comparator but it would not work there. The comparator would function then slow down as the integration capacitor discharged. So the problem was fixed by installing the integration capacitor and diode on the input of the buffer amplifier that fed the reference signal to the comparator.

One other problem that occurred with this circuit was in the integration circuits on the input of the buffer amplifier that feeds the comparator a reference signal (as discussed below) and with the integration circuit on the input of the buffer amplifier that outputs the frequency of the strongest signal to a data acquisition unit. In both cases it was taking too long for these capacitors to discharge over time due to the high input impedance of the buffer amplifiers they were going into. So drainage resistors were installed. A 100 K Ohm drainage resistor was installed on the input of the buffer amplifier that fed the comparator. And a 1 M Ohm resistor was installed in the input of the buffer amplifier that would output the frequency of the strongest signal.

Bench test results

The Frequency vs. amplitude plot separator worked well on the bench. The output of the hex inverter was going high and low in sync with sweep voltage (fig 33). All three shorting transistors in each channel were functioning properly turning the video, sweep voltage, and integrated signals on and off (fig 34). The output of the peak detector is choppy because of capacative discharges (fig 35) but goes up when there is a spike within its bandpass and down when the spike is out of its bandpass. And the frequency circuits are working similarly, locking on to spikes when they enter their bandpass with a choppy output just like the peak detectors from integration capacitive discharges.

Current design

Power enters through the back of the chassis on the system's standard 6 pin female Jones bulkhead connector. The system operates on + 15, -15, and +5 volts. These voltages are switched on by a four way switch on the front panel where a green LED is hooked up to the +15 volt line in series with a 1 K Ohm resistor. Sweep and video signals are inputted through BNC female connectors on the back panel.

The sweep voltage is turned on an off from switches on the front panel for each channel. Sweep voltage goes into a window comparator circuit for each of the four channels where it is divided up. The reference voltages divide up the sweep voltage into four and the comparators output into diodes. The diodes in the window comparator circuits are set up to allow negative voltages to pass instead of positive. Since the output of the window comparator circuits was -15 volts low and 0 volt high, inverting buffer amplifiers were put on the output of each window comparator circuit for each of the four channels. A voltage divider on the output of its inverting buffer amplifiers was used before the input of the hex inverters in each circuit. Diodes were also installed to short out the 1.75 volt leakage voltage on the input of each hex inverter to the output of each inverting buffer amplifier. The TTL output of the hex inverters goes to a decade counter board which has four divide by ten circuits on it using 7490 decade counter IC's. This board is used to drive the gate lights on the front panel to show that each channel is triggering and divides the TTL signal by ten so that the flashing rate is slow enough to notice action. The output of the hex inverters also goes to shorting out the peak detector's integration capacitors. Then the output of the peak detector goes through a diode and a .33 UF integration capacitor to ground and then to a data acquisition unit giving the amplitude of the strongest signal within the set bandpass.

The output of the voltage dividers off of the inverting buffer amplifiers also goes to biasing shorting transistors whose collectors are shorting the video off of a 1 K Ohm resistor on the output of a buffer amplifier where the video is first fed into ground. Off of the collector of each shorting transistor is a diode that feeds into an integration circuit with a .22 UF capacitor and a 100 K Ohm drainage resistor. From there the signal goes into another buffer amplifier and into a comparator on an LM339 comparator IC as a reference voltage. This is compared to the non-integrated video signal and the output of the comparator goes into an inverting buffer amplifier on an LM2902. The output of this biases another NPN shorting transistor. The sweep voltage is fed into a buffer amplifier and then through a 47 K Ohm resistor and to the collector of that shorting transistor. Off the collector the signal goes through a diode and into an integration circuit of a .22 UF cap and a 1 M Ohm resistor to ground. This feeds into another buffer amplifier whose output goes to a data acquisition unit giving the frequency of the strongest signal within the set bandpass.

Power Supply

Problem

I needed a power supply for all of this equipment. This power supply could not be switching because the harmonics produced from switching power supplies would disturb the front and back ends of the spectrum analyzer. And the power supply had to put out +5, +12, +15, -15, and +24 volts of at least one amp each.

Hypothesis

In order to construct a power supply to fit the above specifications I would use numerous linear power supplies already in the junk box at the desired voltages under one enclosure. This would not give off the harmonics switching power supplies do and would save huge amounts money from having to buy a new power supply that could handle all of the desired voltages.

Design, problems, solutions, and design changes

Three power supplies were chosen. One put out +15 and -15 volts at 1 amp, another that supplied +5 volts and +24 volts at 1 amp each, and a third that supplied +12 volts and -12 volts at 2 amps. These power supplies were rated for 1 amp fuses off of their primary coils and no fuse was needed for the outputs. I built a fuse panel on the door of the old telephone line enclosure salvaged off of the wall in the control room. This enclosure worked perfectly for fitting all three power supplies. I also added fuses on the outputs for the power supplies to be safe even though the current limiting circuitry works better than fuses. I used 14 gauge wire throughout the power supply box. I found a 15 amp switch I used for power which is well overrated for its maximum of 3 amp load needed. I also purchased a neon lamp for a power indicator and placed it next to the power switch on the side panel.

There were absolutely no problems with the power supply except that I did not include -15 volt output at first but it was added later.

Bench test results

The bench test turned out good. I left the power supply on for long periods of time while I was working on other systems in on my workbench. There is some warmth to it after about 6 or 7 hours but not much, it is hardly noticeable above room temperature. All the voltage outputs also stayed stable after long periods of time.

Current Design

The power supply is made up of three different linear power supplies (fig 36). 120 volts AC line voltage enters the box from a grounded power cord through a Heyco strain relief. The power cord is 16 gauge wire, and is hooked right into a screw terminal bus. The bus is hooked up to the main power switch. The switch controls the neon power indicator and the power of all the other supplies through 1 amp fuses on each supply. The outputs of the power supplies each go onto the fuse panel mounted on the door, then to a screw terminal bus and back to the main chassis through a system standard power connector, female 6 pin Jones bulkhead.

The Cabling System

Problem

The new receiving system needed a good way to utilize all of the wires in each cable going up to the dish on the roof. This system had to be organized and all outside connections waterproofed because of problems encountered in previous years with cables not waterproofed. There had to be a way to control the power on the roof and calibration devices. This was not possible in previous years. I also wanted to design an intercom link to talk to the control room, which was not possible in past years.

Hypothesis

A junction box was designed for the control room with every wire attached to a different position on screw terminal blocks. And another junction box was designed for the roof, one that was hermetically sealed, with waterproof connections from the cables into the box. The box needed a control panel where the front end power could be turned on and off, the actuator arm controlled, the calibration controlled, an intercom installed, and test points available for all key wires.

Design, problems, resolution, and design changes

I finally found a suitable enclosure for the roof junction box at a swap. It was a radio test set, brand new military surplus straight out of the bag. It came with all the military cables and connectors. The hermetically sealed box even had the mating ends of all the connectors attached to the cables. There was a panel of switches, test points, 24 volt lights, and silver plated BNC bulkhead connectors inside. I scraped the enamel off of the panel and painted it gray to get rid of the old labels. I put switches and lights in different locations for my application. I purchased four screw terminal blocks for all the wires off the military bulkhead connectors on the box in order to utilize every pin on all the connectors. I then wired each pin to a position on the terminal blocks. Next I designed the front panel.

The front panel consisted of two double poled switches for power of +12, +24, +15, -15, and +5 V and was switched on by a relay powered off the +12 V line. Fuses were installed at 1 amp each for every voltage on the front panel so they were easily replaceable. Test points were installed on the fuses and 24 volt lamps were placed next to each fuse and test point to indicate power. The only problem here was that the 24 volt lamps only worked at full brightness with 24 volts. So a lamp driver board was designed (fig 37) and bias resistor values were calculated for each driver using Ohm's law where 47 K Ohm is the optimum bias resistor value at +12 volts. The values turned out to be about 47 K ohm at +15 and -15, and 22 K Ohm at +5V. Lamp drivers were also needed for the +5 volt TTL going down to the control room for the controls for moving the actuator arm. The lamp driver board was assembled and worked.

An intercom jack was installed. And a silver plated BNC bulkhead was also installed to monitor the video signal from the roof while doing work on the receiver. Extensive pin out charts were also made of all cables and connectors to keep good track of wires.

Bench test results

The box was time tested on the bench. The lamp driver board's NPN and PNP driver transistors became mildly warm. And the lamps also became warm. Everything was well within its operating specs and the box was ready for installation on the roof.

Current design

The current design is practical (fig 37). Power and other miscellaneous signals come into the box through military bulkhead connectors. There is a position on the screw terminal buses for each pin off the military connectors. These screw terminal buses are to be wired together accordingly for future modifications. Power is switched on and off for the downconverter from this box on the front panel. The power first goes to the power switches and relay on the front panel. When switched on each voltage goes through a fuse at 1 amp then to a test point and to the front end through a military bulkhead connector. The voltages also go to a lamp driver board that turns on the 24 volt lamps accordingly to the lower bias voltages. There is a two way single pole switch for North and South connected to a momentary switch hooked up to +5V. There are two lines going back into the control room junction box so that when one is biased from the North South switch and momentary switch combination the actuator arm will move the dish North or South accordingly. There is also an intercom and a video output jack that are wired into the bus and out the military connectors through the miscellaneous signals cable.

The System

Problem

The individual subsystems were now ready to be put together into the system. The system had to be neatly mounted though. Chassis had to be placed together for short cable runs and self contained so that things do not become a mess. The main problem is that all the systems must work well together.

Hypothesis

In order to keep things neat and cable runs short, the system was mounted in a standard 19 inch rack. And the system should work well together after assembling all the subsystem components.

Design problems, solutions, and design changes

A rack was donated the Big Ear observatory this past summer. It is a dual 4 foot high rack and the equipment fills it nicely. A wiring harness was made out of 16 gauge wire to distribute power to all rack mounted chassis from the power supply. The power supply was mounted off the side in the rack. Two pieces of angled hardened steel were cut by my friend Kevin to hold up the heavy TRM-3 sweep generator in the rack. The TRM-3 was modified to output fixed and varied sweep voltage from its sweep oscillator (fig 38) output for the rest of the system to operate from. BNC cables were made to route the video and sweep voltage signals. A shielded cable with a 15 pin "D" type make connector was found and used to connect to the 15 pin "D" type bulkhead connector that output data from the Frequency vs. amplitude plot separator. All of these cables were wire tied together into a large wiring harness. A junction box was also made that plugged into the power supply and provided for two system standard 6 pin Jones female bulkhead connectors so the roof power could also be hooked up to the system's power supply.

Some problems that occurred were in the low sweep voltage out of the sweep generator. This was affecting the frequency vs. amplitude plot separator and the problem was solved by adding an amplifier to the sweep input of the frequency vs. amplitude plot separator (fig 32).

There was a problem with the video signal being inverted so an inverting buffer amplifier was installed on to the video amplifier board (fig 22). This was affecting the Frequency vs. amplitude plot separator also but the problem was resolved.

Another problem that occurred within the system was that the IF amp in the third stage was being saturated easily. This was because the HP square law detector was pulling down the signal coming out of the IF amp too much to the point where it also brought down the saturation level of that amplifier. This was resolved by turning up the Mini Circuits programmable attenuator to keep the IF below saturation levels.

Field test results

At first test the Frequency vs. amplitude plot separator was giving out weak voltages on its outputs as indicated in the first scan with the entire system (fig 39). The problem was a short in wires I hooked up too quickly into the input module of the Fluke data acquisition unit.

The next two scans (fig 40, 41) indicated questionable Frequency vs. amplitude plot separator performance. Even though the output voltages were high the data looked strange. And this is where the saturation problem was found and solved with the video signal. The video signal would not rise past a certain point (fig 42) over long periods of time. The programmable attenuator was turned up even more and fixed this in the last scan (fig 43). But the frequency vs. amplitude plot separator needed more work. After hours of trouble shooting I found that two integration capacitors in each channel of the Frequency vs. amplitude plot separator were draining too slow causing false readings- ones that would not change very much over time. So this was fixed by adding a 1 M Ohm and 100 K Ohm resistors to two different places on the frequency portion of the channels. The last scan collected indicated a big change in performance proving that the frequency vs. amplitude plot separator now was fully operational (fig 44).

Current design

The downconverter feeds into the IF Chassis, and the IF Chassis is tuned by the TRM-3 sweep generator. The video output of the IF Chassis goes into the Filter Chassis along with the varied sweep output of the TRM-3. The Filter Chassis' video output goes into the frequency vs. amplitude plot separator and into the vertical input of the TRM-3. The fixed sweep output from the TRM-3 is also inputted into the Frequency vs. amplitude plot separator. The Frequency vs. amplitude plot separator outputs 8 different voltages, 2 per channel. Each channel outputs the frequency of the strongest signal in its ¼ of the bandpass and the strength of that strongest signal. This data is then inputted into the Fluke data acquisition unit and that is hooked up to the 486 dx 33 computer for data collection. DC power is distributed from the power supply to the rooftop junction box, the IF Chassis, the Filter Chassis, and the Frequency vs. amplitude plot separator. The rooftop junction box controls the power to the downconverter box. Line voltage first enters the rack though a rack mounted power distribution panel that is relay controlled. From here line voltage of 120 volts AC is distributed to the power supply, TRM-3, and the Fluke data acquisition unit.

Signal Generator

Problem

Now that the system was ready I had to construct a device to test everything. This device must be able to create strong and weak signals that are to be transmitted to the feed horn into the system not directly injected into the front end.

Hypothesis

A signal generator was designed to accomplish the above. This signal generator uses a Mini Circuits POS-2000 and a Mini Circuits TOAT-51020 programmable attenuator. The attenuator should weaken the signal as necessary and the VCO should be able to strongly oscillate within the 1400 MHz range.

Designs, problems, solutions, and design changes

The main design was to control the VCO by a precision ten turn 10k ohm potentiometer set up as a voltage divider. The output of the VCO would feed into the programmable attenuator. And the attenuator's TTL would be controlled by three switches on the front panel.

This design was good except for the supply and maximum tuning voltages of the VCO (fig 46). The Mini Circuits POS-2000 VCO has a maximum supply voltage of +10 volts. This was a problem considering the power available from the signal generator's soon to be power supply. The supply would output +5 volts, +12 volts, -12 volts, and +24 volts. So a voltage regulator had to be installed in the voltage input pin of the VCO. Since I could not find any voltage regulators left in the "10v reg" drawer I had to build on from scratch. A formula was obtained from the 1994 ARRL Handbook for building a voltage divider with a zener diode. In the formula the amount of current draw, input voltage, and zener diode voltage were all held constant where the limiting resistance was calculated. The POS-2000 VCO draws a maximum of 4.5 ma but I solved the equation for 7.0 ma to give a little room for error. With an input voltage of +12 volts, a current draw of 7.0 ma, and a zener diode voltage of 10 volts the formula came out to be about 200 ohms.

$Rs = (Vin - Vzener) / (1.1 \times I)$

$Rs = (12 \text{ volts} - 10\text{volts}) / (1.1 \times .007 \text{ amps}) = 200 \text{ ohms}$

Another problem was in the maximum input voltage of that same VCO. The maximum input voltage was +22 volts and the power supply did not supply this. So using the +24 volt side of the supply I calculated out a voltage divider formula where I solved for R1 keeping R2 constant at 10k ohms because this was my precision potentiometer for tuning.

$Vout = Vin \times R2 / (R1 + R2)$

This ended up to be 909.1 ohms. So a 900 ohm resistor was put in series with the precision potentiometer for tuning.

Bench test results

The signal generator worked perfectly on the workbench. The programmable attenuator was lowering the signal output and the VCO appeared to be changing in frequency when adjusted by the tuning potentiometer.

Field test results

In the field the signal generator also performed very well. A small calibration antenna was newly installed onto the dish. This was hooked up to the signal generator after about a 200 foot cable run. When the system was on and the signal generator tuned into frequency a spike could be viewed on the spectrum output of the sweep generator. This indicated the signal generator was working and doing its job by being detected by the system.

Current design

The current design is very straight forward (fig 45). The VCO is controlled by a precision potentiometer. The output of the VCO is fed into a programmable attenuator. The output of the attenuator goes out the front panel. Power comes in through a system standard 6 pin Jones female bulkhead connector on the back panel. There is a four way switch which turns on +5 volts, +12 volts, and +24 volts to the circuitry. A power indicator LED is attached to the +12 volt side of the power switch. +12 volts goes into a voltage regulating circuit which powers the Mini Circuits POS-2000 VCO. The +24 volt side goes into a voltage divider which is used for the VCO control voltage controlling the frequency of the signal generator. And the +5 volt side goes into the TTL control switches and LED's which control the programmable attenuator. +5 volts is also distributed to the programmable attenuator's +5 volt input.

Capacitors were placed on the input and output of the voltage regulator and on the +5 volts input into the programmable attenuator. Semi rigid 402 was soldered to the bottom of the board to connect the RF sections of the two Mini Circuits parts. 4.7 K ohm resistors were put in series with the TTL switches and the programmable attenuator on the front panel of the signal generator. Three LED's were also hooked up off the TTL switches with 470 Ohm resistors. A switch was installed to switch between the potentiometer and an exterior VCO control voltage. And finally semi rigid 402 was placed from the signal generator board to the SMA female bulkhead connector on the front panel.

Conclusion

According to the data collected off of the video signal (fig 43) and the Frequency vs. Amplitude Plot Separator (fig 44), the system is performing well. A strong 75 MHz IF output is indicated from the saturation of the IF Chassis. The IF is not saturating the receiver which is also indicated in the last scan (fig 43).The final data collected off of the Frequency vs. Amplitude Plot Separator indicates the frequencies of the four strongest signals and their signal strength. The Filter Chassis is also operational, but because of lack of data needed to accurately set the filters the Filter Chassis, could not be field tested in the system. The Cabling System works well. There were no lose wires at any time during data collection and power made it to the Downconvertor. Also the power supply was on for about one week straight without failure and it did not overheat.

The data collected off the system with the simulated RFI signal injected by the signal generator shows that the system does in fact receive at the 1400 MHz frequency range, is able to detect RFI spikes over time, and is able to filter them out. This is shown in scan 11. The scan was started at 7:05 PM. This ran for a while until 7:14 PM when the signal generator was turned on. Then at 7:22 PM a filter was set to knock out the RFI created by the signal generator. At 7:42 PM the signal generator was turned off. At 7:50 PM the filter was turned off. And finally at 7:56 PM the scan was stopped. When the scan was compiled and printed out it was evident when the signal generator was turned on and when the filter was set (fig 47). The initial rise of signal strength indicates the signal generator being powered up. The drop in that strong signal indicates the filter being turned on to eliminate this signal. In addition, the differentiation in frequency indication and peak signal strength in each of the voltages graphed indicates the Frequency vs. Plot Separator is functioning properly. The system is fully operational in detecting and eliminating RFI.

Bibliography:

The Radio Amateur's Handbook, 1942. West Hartford Connecticut: American Radio Relay League, INC, 1939.

The Radio Amateur's Handbook, 1970. Newington, Connecticut: American Radio Relay League, INC, 1969.

The Radio Amateur's Handbook, 1977. Newington, Connecticut: American Radio Relay League, INC, 1976.

The Radio Amateur's Handbook, 1981. Newington, Connecticut: American Radio Relay League, INC, 1980.

The Radio Amateur's Handbook, 1994. Newington, Connecticut: American Radio Relay League, INC, 1993.

Carr, Joseph J. Secrets of RF Circuit Design. Blue Ridge Summit, PA: TAB Books, 1991.

Sedra, Adel S. and Kenneth C. Smith. Microelectronic Circuits 2nd ed. New York: CBS College Publishing, 1987.

Patrick, Dugger, and Suess Ziegler. "Communications." Basic Electronic Systems Technology. Beverly Hills, California: Bruce, 1973.

MOTOROLA Linear/Interface Integrated Circuits. Phoenix, Arizona: MOTOROLA INC. 1983.

1986 Linear Databook. Milpitas, CA: Linear Technology Corporation, 1985.

Mims, Forrest M. "Op Amp IC Circuits." Engineer's Mini-Notebook. US: Siliconcepts, 1985.

Mims, Forrest M. "Digital Logic Circuits." Engineer's Mini-Notebook. US: Siliconcepts, 1986.

Mims, Forrest M. Getting Started in Electronics. US: Siliconcepts, 1986.

Technical Manual for Spectrum Analyzer TS-1379 A/U. Department of the Navy, Naval Ship System Command, 15 October 1966.

Technical Manual for Generator, Sweep SG-24/TRM-3. Department of the Navy, Beureau of Naval Weapons, 10 December 1956.

Math, Irwin WA2NDM. "A 'Poor Man's' Method For Simple Antenna Pattern Measurements." CQ Ameteur Radio. November 1996: 58-59.

Spiwak, Marc. "Build a Temperature Adapter For Your DMM." Popular Electronics. January 1997: 48-50.

Hayward, W. H. Introduction to Radio Frequency Design. (unknown)

Acknowledgments

A special thanks to:

- My parents
- The radio astronomy club's administrator
- Steve Cameron
- Dr. Daniel Fleisch
- Steve Murphy
- Dr. Phil Barnheart
- Charlie
- Rick Smith
- Ken Ginger
- Paul Swetnam
- Steve Brown
- Barney Nefcy
- Everyone at Aeroflex LINTEK

PROJECT LOGS

DATE	TIMES			TOTAL # OF HOURS
6/8/95	400PM - 800PM			4
12/6/96	120PM - 207PM			0.78
12/9/96	300PM - 430PM			1.5
12/9/96	120PM - 207PM			0.78
12/10/96	610PM - 800PM			2.78
12/10/96	120PM - 207PM			0.78
12/11/96	120PM - 207PM			0.78
12/12/96	120PM - 207PM			0.78
12/13/96	1000PM - 1200AM			2
12/13/96	120PM - 207PM			0.78
12/15/96	200PM - 330PM			1.5
12/16/96	300PM - 530PM			1.5
12/16/96	120PM - 207PM			0.78
12/17/96	510PM - 800PM			2.78
12/17/96	120PM - 207PM			0.78
12/18/96	120PM - 207PM			0.78
12/19/96	615PM - 700PM			0.75
12/19/96	120PM - 207PM			0.78
12/20/96	120PM - 207PM			0.78
12/21/96	150PM - 500PM	1200AM -		3
12/22/96	300PM - 600PM	925PM - 240AM		8.25
12/23/96	430PM - 450PM	100AM - 300AM		2.33
12/24/96	1200PM - 1245PM			0.75
12/27/96	540PM - 700PM			1.33
12/28/96	120AM - 230AM			1.166666667
12/30/96	400PM - 830PM			2.5
1/2/97	430PM - 705PM			2.5
1/3/97	430PM - 800PM	1140PM - 1200AM		3.83
1/4/97	1230AM - 305AM			2.5
1/6/97	120PM - 207PM			0.783333333
1/7/97	120PM - 207PM			0.78
1/8/97	1005AM - 1052AM	120PM - 207PM		1.563333333
1/9/97	610PM - 800PM			1.833333333
1/9/97	1005AM - 1052AM	120PM - 207PM		1.56
1/10/97	1005AM - 1052AM	120PM - 207PM		1.56
1/13/97	1005AM - 1052AM	120PM - 207PM		1.56
1/14/97	1005AM - 1052AM	120PM - 207PM		1.56
1/15/97	1005AM - 1052AM	120PM - 207PM		1.56
1/16/97	1005AM - 1052AM	120PM - 207PM		1.56
1/17/97	800PM - 1200AM			4
1/17/97	1005AM - 1052AM	120PM - 207PM		1.56
1/18/97	455PM - 700PM			2.083333333
1/19/97	945AM - 130PM			3.75
1/19/97	1100AM - 100PM			2
1/20/97	700PM -			

5/10/97

PROJECT LOGS

DATE	TIMES			TOTAL # OF HOURS
6/8/95	400PM - 800PM			4
10/24/96	120PM - 207PM			0.78
10/25/96	120PM - 207PM			0.78
10/28/96	1120PM - 1140PM			0.33
10/28/96	120PM - 207PM			0.78
10/29/96	120PM - 207PM			0.78
10/30/96	1150AM - 100PM			1.18
10/30/96	120PM - 207PM			0.78
10/31/96	120PM - 207PM			0.78
11/1/96	120PM - 207PM			0.78
11/2/96	1000PM - 100AM			3
11/4/96	120PM - 207PM			0.78
11/5/96	120PM - 207PM			0.78
11/6/96	120PM - 207PM			0.78
11/7/96	430PM - 630PM			2
11/7/96	120PM - 207PM			0.78
11/8/96	930PM - 1200AM			2.5
11/8/96	120PM - 207PM			0.78
11/9/96	600PM - 1200AM			6
11/11/96	120PM - 207PM			0.78
11/12/96	315PM - 400PM			0.75
11/12/96	120PM - 207PM			0.78
11/13/96	300PM - 400PM	1055PM - 1130PM		1.5
11/13/96	120PM - 207PM			0.78
11/14/96	1000PM - 1200AM			2
11/14/96	120PM - 207PM			0.78
11/15/96	700PM - 800PM	1045PM - 1200AM		2.25
11/15/96	120PM - 207PM			0.78
11/16/96	1000PM - 210AM			4
11/18/96	120PM - 207PM			0.78
11/19/96	700PM - 745PM			0.75
11/19/96	120PM - 207PM			0.78
11/20/96	120PM - 207PM			0.78
11/21/96	120PM - 207PM			0.78
11/22/96	120PM - 207PM			0.78
11/23/96	230PM - 415PM	600PM - 850PM		3.5
11/24/96	320PM - 600PM			2.67
11/25/96	120PM - 207PM			0.78
11/26/96	900PM - 1000PM			1
11/26/96	120PM - 207PM			0.78
11/27/96	120PM - 207PM			0.78
12/2/96	120PM - 207PM			0.78
12/3/96	120PM - 207PM			0.78
12/4/96	120PM - 207PM			0.78
12/5/96	120PM - 207PM			0.78

PROJECT LOGS

DATE	TIMES			TOTAL # OF HOURS
6/8/95	400PM - 800PM			4
8/25/96	800AM - 915PM			13.25
8/26/96	900PM - 1200AM			3
8/27/96	200PM -200AM			12
8/28/96	1100PM - 1200AM	100AM - 230AM		2.5
8/29/96	1215PM - 300PM	915PM - 1200AM		5.5
8/30/96	1145AM - 1200PM	100PM - 300PM	515PM - 1130PM	9
8/31/96	145PM - 1030PM			7.75
9/1/96	300PM - 100PM			2
9/3/96	930PM - 1130PM			2
9/21/96	115PM - 340AM			14.33
9/23/96	120PM - 207PM			0.78
9/24/96	120PM - 207PM			0.78
9/25/96	120PM - 207PM			0.78
9/26/96	120PM - 207PM			0.78
9/27/96	120PM - 207PM			0.78
9/30/96	500PM - 700PM			2
9/30/96	120PM - 207PM			0.78
10/1/96	120PM - 207PM			0.78
10/2/96	850PM - 1100PM			2.18
10/2/96	120PM - 207PM			0.78
10/3/96	120PM - 207PM			0.78
10/4/96	1130PM - 1200AM			0.5
10/4/96	120PM - 207PM			0.78
10/5/96	215PM - 330PM			1.25
10/6/96	200PM - 530PM			3.5
10/7/96	120PM - 207PM			0.78
10/8/96	120PM - 207PM			0.78
10/9/96	950PM - 130AM			3.67
10/9/96	120PM - 207PM			0.78
10/10/96	120PM - 207PM			0.78
10/11/96	745PM - 200AM			6.25
10/11/96	120PM - 207PM			0.78
10/12/96	1030PM - 200AM			3.5
10/14/96	120PM - 207PM			0.78
10/15/96	1135PM - 100AM			2.5
10/15/96	120PM - 207PM			0.78
10/16/96	120PM - 207PM			0.78
10/17/96	120PM - 207PM			0.78
10/18/96	120PM - 207PM			0.78
10/19/96	730PM - 100AM			5.5
10/20/96	800PM - 1200AM			4
10/21/96	120PM - 207PM			0.78
10/22/96	120PM - 207PM			0.78
10/23/96	120PM - 207PM			0.78

PROJECT LOGS

DATE	TIMES			TOTAL # OF HOURS
6/8/95	400PM - 800PM			4
6/15/95	600PM - 900PM			3
4/14/96	200PM - 600PM			4
4/15/96	400PM - 800PM			4
4/16/96	700PM - 100AM			6
6/3/96	330PM - 800PM			4.5
6/4/96	500PM - 630PM			1.5
6/5/96	1100PM - 1200AM			1
6/7/96	520PM - 600PM			0.67
6/8/96	700PM - 800PM			1
6/9/96	1200PM - 400PM	620PM - 800PM		5.67
6/10/96	1230PM - 300PM	1030PM - 1200AM		4
6/11/96	1020PM - 1200AM			0.67
6/13/96	1130PM - 1215PM	440PM - 530PM	120AM - 220AM	3
6/25/96	700PM - 900PM			3
6/27/96	615PM - 100AM			6.75
6/28/96	900PM - 1020PM			1.33
6/29/96	600PM - 1020PM			4.33
6/30/96	1000AM - 100PM	140PM - 400PM		5.33
7/13/96	1230PM - 130PM			1
7/14/96	930PM - 1110PM			2.67
[illegible]15/96	715PM - 830PM			1.25
[illegible]16/96	500PM - 530PM	715PM - 900PM		2.25
7/17/96	710PM - 905PM			2
7/18/96	500PM - 600PM			1
7/19/96	1115PM - 1200AM			0.75
7/21/96	1145AM - 130PM			1.75
7/23/96	545PM - 630PM			0.75
7/24/96	600PM - 700PM			1
7/25/96	500PM - 600PM			1
7/26/96	500PM - 600PM			1
7/27/96	300PM - 130AM			10.5
7/28/96	1000AM - 400PM	500PM - 915PM		10.25
7/29/96	500PM - 700PM			3
7/30/96	500PM - 900PM			4
7/31/96	500PM - 600PM	800PM - 900PM		2
8/3/96	115PM - 320PM	700PM - 1245AM		7.75
8/4/96	1100AM - 400PM	700PM - 930PM		7.5
8/5/96	730PM - 930PM	100PM - 1130PM		3.5
8/6/96	900PM - 1100PM			2
8/9/96	1000PM - 100AM			3
8/10/96	100PM - 100AM			12
8/22/96	800AM - 1015PM			14.25
[illegible]3/96	800AM - 1030PM			14.5

5/10/97

PROJECT LOGS

DATE	TIMES			TOTAL # OF HOURS
[illegible]/3/95	400PM - 800PM			4
1/20/97	1005AM - 1052AM	120PM - 207PM		1.56
1/20/97	220PM - 430PM			2.2
1/21/97	200PM - 245PM			0.75
1/22/97	645PM - 1045PM			4
1/23/97	740PM - 830PM			1
1/24/97	445PM - 900PM			4.25
1/25/97	1250PM - 125AM			12.5
1/26/97	320PM -600PM	700PM - 1145PM		7
1/30/97	640PM - 845			2
1/31/97	700PM - 815PM	1025PM - 1200AM		3
2/1/97	130PM - 330PM	1030PM - 1150PM		3.2
2/3/97	1050PM - 1200AM			1
2/5/97	1045PM - 130AM			3
2/8/97	230PM - 300PM			0.5
2/9/97	245PM - 530PM			3
2/13/97	610PM - 810PM			2
2/15/97	1200PM -630PM	1135PM - 100AM		8
2/16/97	645PM - 1140PM			5
2/20/97	955PM -1100PM			1
2/21/97	1130AM - 510PM			5.5
2/22/97	135PM - 200PM			0.5
2/23/97	950AM - 1200PM			2
[illegible]8/97	1030PM - 100AM			2.5
3/1/97	1000PM - 200AM			4
3/2/97	930PM - 200AM			4.5
3/4/97	315PM -400PM			0.75
3/5/97	530PM - 900PM			3.5
3/7/97	1130PM - 200AM			2.5
3/9/97	800PM - 1230AM			4.5
3/10/97	800PM - 1000PM			2
3/11/97	1000PM - 130AM			3.5
3/13/97	1100PM - 1145PM			0.75
3/14/97	1250PM - 115PM	535PM - 610PM		1
3/15/97	1200PM - 330PM	600PM - 200AM		11.5
3/16/97	215PM - 1100PM			9
3/20/97	555PM - 800PM			2
3/23/97	1255AM - 130AM	1145AM - 200PM		2.75
3/23/97	400PM - 400AM			12
3/24/97	330PM - 1000PM			6.5
3/25/97	905PM - 230AM			5
3/26/97	300PM - 600PM	900PM - 445AM		11
3/27/97	300PM - 1100PM			8
4/7/97	300PM - 500PM			2
4/8/97	300PM - 900PM			6
4/9/97	300PM 1000PM			7
4/10/97	300PM - 1000PM			7
4/11/97	300PM 1230AM			9.5
[illegible]2/97	1200PM - 200AM			12

5/10/97

PROJECT LOGS

DATE	TIMES			TOTAL # OF HOURS
6/3/95	400PM - 800PM			4
4/13/97	1100AM - 400AM			17
4/14/97	300PM - 230AM			11.5
4/15/97	900AM - 630PM			9.5
5/4/97	1200PM 400PM			4
				680.56

5/10/97