RADIO ASTRONOMY

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Journal Contents

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~ The President's Page ~

November is almost over and my wife Lynn and I are at our vacation home in the Chiefland Astronomy Village. www.chiefland.org I've been working on getting my radio astronomy projects back on-line and adding to the projects with Jovian and solar monitoring and VLF solar monitoring. With ten acres to string antennas, developing projects is fun. Paul Oxley finished my RA receiver and I have been solar testing with a 90 cm dish. So far testing is going well. I'm also in the process of updating my 3-meter dish with hardware and software changes. All in all, I expect a productive winter with RA projects.

With the economy dropping faster than the winter temperature, there are several low cost RA projects that members can start on in the warmth. With solar minimum behind us, it's a great time to get started in solar monitoring. Radio Jove is a low cost way to get started if you have a HF receiver. Check http://radiojove.gsfc.nasa.gov for how to get started. Another low cost opportunity is VLF; a complete setup can be built for just a few hundred USD. Check NASA Inspire, http://image.gdfc.nasa.gov/poetry/inspire, and the Stanford University project at http://solar-center.stanford.edu/sid/.

Jim Brown has revamped the SARA Mentor program. If you need help, check the SARA web site for Mentors in your geographic area or area of specialty. If you are interested in helping in mentor member projects, contact Jim is at starmanjb@comcast.net. Jim has also updated the SARA brochure and it is on the SARA web page. Check it out; it's in PDF format. It may be downloaded and handed-out to folks interested in SARA and in radio astronomy.

73's

Tom Crowley KT4XN

~ From the Editor's Desk ~

The cover color depicts mood. We hope you liked the summer sky blue cover of the last issue. The melancholy mood of fall has prompted the lavender you see in this October/November issue. As always, the editorial staff thanks those who took the time to drop a quick note. We always appreciate that. We will gladly accept submissions preferably formatted in Microsoft Word, even for blurbs; otherwise, we would have to spend much time reformatting the e-mail text because of the numerous hard returns inserted by the outgoing server. Please allow sufficient lead-time for our review of your technical papers, hands-on project tips, analytical tools, and reviews of books, web pages, software, hardware, etc. You will find some of the guidelines here, http://radio-astronomy.org/publicat/authjrnl.pdf. Please be mindful of the file size by reducing your figures to less than 100 kB, if possible. Insert your reduced figures in your document. I also want to stress the use of spell-checker. And please, use only one space between words, between sentences, and between a numerical value and its unit. Thanks for your support and cooperation.

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Encouraging feedback is always good to hear, as noted above. We are thankful to all—readers, authors, leaders—for the good things said about this Journal. Dr. Stan Kurtz, a professional radio astronomer and contributor to this issue, recently wrote to me,

Indeed, you ARE thorough! I think you did a better job of editing the text I sent you (in terms of consistency of style, correct location of commas, etc) than I have sometimes seen in Astrophysical Journal, and definitely in Astronomy & Astrophysics!

And the Program Director for the SID monitor program, Deborah Scherrer, at Stanford Solar Center, complemented us,

I looked at your [SARA] website and it appears you have a large and active group! I did enjoy seeing the copy of your journal as well. Very few clubs can pull off a full-fledged journal, so you are to be commended!

Editing this Journal often requires finding images and url links to help the readers. Bob Culbertson (WA3YGQ), a contributing author in the last issue (*Amateur Meteor Radio Astronomy: History & Theory*), said

Thanks for all you did with the article.

And we thank him!

***

This issue begins a series on amateur radio interferometry. Dr. Stan Kurtz, with Dr. David Fields, have written a superb paper on the VLA. Jan Lustrup of Norway demonstrates his C-band interferometer, complemented with sketches, pictures, and analyses by the editorial staff. Building lightning detectors rounds out the full-length features in this issue. It might be a good project for some of us during the cold winter months anticipating the spring storms to test out the detector. Solar Radio Astronomy Miscellany has a plethora of resources that will be useful for the avid hobbyist. Finally, it gives me great pleasure to talk about Dr. Jocelyn Bell Burnell's blending of science and literary arts. You will be delighted by her radio broadcast and new book.

***

In the last issue, we saw that the August 1, 2008 total solar eclipse had produced ionospheric effects, even on the night side. This had been suspected by some researchers:

Though the path of totality is in very northern areas, research has found that the Earth's ionosphere responds to eclipses in both hemispheres, on both the day and night side of the Earth! So SID space weather monitors in many places of the world may be able to detect this eclipse. We are hosting a SID campaign for 1 August and, if your SID monitor is working, we would like you to join us!
(Stanford Solar Center, http://solar-center.stanford.edu/SID/educators/eclipse.html).

Of course, we forwarded our SID monitor data to Stanford, together with a copy of our work (J. Mannone, B. Lord & M. Lord) in Aug/Sep 2008 issue of the Journal. In mid October, these things invoked encouraging responses from Deborah Scherrer, the SID Solar Weather Monitor Program director, including good words about the SARA Journal (see above), our SID observations and research, a desire for corroboration and a willingness to contribute a future article. A digest of responses follow:

Thank you so much for sending along SARA's Radio Astronomy journal. I read both your article and Jan Lustrup's. Found them very intriguing. As you probably know from the articles on our SID eclipse website, researchers have been able to detect effects of a solar eclipse, even on the dark side of the Earth's ionosphere. But there was nothing in those articles about an increased signal enhancement on the day before the eclipse, as you had found. Nor would I have expected to see such a slow recovery on the following day. And, again as you noted, the nightside thinning of the F layer is also a mystery.

We did amass a collection of SID data for the eclipse date, and before and after. Most of our sites were on the dark side of the Earth during the eclipse, as you were. But we are still hoping to see effects, as you did. I am not a researcher, but my solar scientist friend and colleague, Bala Poduval, is examining our SID eclipse data…perhaps you and she can share ideas… We would love to include your data in our analysis…

Again, thanks so much for the information about your eclipse responses! I hope you and Bala can find more intriguing discoveries as you go through the additional data.

When the Lords solicited her for an article for the Journal,

Sure, I would love to write a little article about you and your group [that] could be useful. But first, let's decide what you would like to take on. Your interest is in expanding the [out]reach of the SID monitor program, and there are many forms that could take. One thought I had was to offer you and your groups' expertise as Mentors, especially to some of our sites in Developing Nations. Your group could provide email support to sites just ringing up their monitors. They often have questions about orienting their antenna, analyzing their data, etc.

***

Kudos to SARA founder, Jeff Lichtman (KI4GIY), in his exciting business contacts to promote radio astronomy (see page 10 for contact information),

Have been contracted to speak (Radio Astronomy and SETI) at the FL Museum of Science on 12/12 - 12/14. Will be setting up equip and talking in six one hour sessions over those days.

And to Jim Sky for his November 19 release of upgraded software,

I am releasing version 2.0 of my Radio-SkyPipe data collection software. There are many new features and improvements. This is a major jump in capability. You can install this along side your Radio-SkyPipe 1.X and use it independently. You will want this software whether you have the Free or Pro version of RSP1.
Please see: http://radiosky.com/skypipeishere.html for details.

In addition, congratulations to Jim Brown, for his upgrade to the SARA Brochure, now available for download from our website (see page 10 for contact information).

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December/January Issue continues the interferometry series, which will include some novel designs/projects for the amateur. In addition, the issue will feature the cosmic microwave background radiation.

John C. Mannone, Senior Editor

~ SARA 2009 Annual Conference ~

The Society of Amateur Radio Astronomers (SARA) 2009 Annual Meeting and Technical Conference will be held Sunday June 28 through Wednesday July 1, 2009* at the National Radio Astronomy Observatory (NRAO), Green Bank WV.

Conference Registration Fees: $165** US (early registrants prior to May 31, 2009, add 15% for late registration, including walk-ins). The Conference fee includes—

Conference registration
2009 SARA membership dues
Conference Proceedings (one hard copy to be distributed at the meeting)
Morning and afternoon coffee & snacks; evening refreshments
Eight meals in the cafeteria

See http://radio-astronomy.org/meetings/grbank09.htm for more details.

Conference Call for Papers: Papers on radio astronomy hardware, software, education, research strategies, and philosophy are welcome. Instructions for preparation and submission of final manuscripts appear in a *Guidelines for Submitting Papers* document on the SARA website, http://radio-astronomy.org/meetings/cfp2009.htm. Please note the following deadlines:

Sunday March 1, 2009: Email a letter of intent, including a proposed title and informal abstract or outline (not to exceed 100 words) to the SARA vice president.

Wednesday, April 1, 2009: First-draft manuscripts due. (Expect feedback, acceptance, or rejection via emails within two weeks.)

Friday May 1, 2009: Final edits of accepted papers must be camera-ready. (Due to printer's deadlines, manuscripts received after that deadline will not make it into the Proceedings.)

Keynote Speakers announced moments before this issue went to "press": With great pleasure, we announce Dr. Jill Cornell Tarter of the SETI Institute (and her alter ego, Dr. Eleanor Arroway) to speak at the 2009 SARA Conference. More details will be forthcoming in subsequent issues of the Journal. In the meantime, I plan to read Carl Sagan's book, *Contact*, and see the movie by the same name, once again before the Conference!

* Conference immediately follows *StarQuest*, the Green Bank Star Party.
** SARA Life Members and those who have already paid their 2009 membership dues prior to registering may deduct $20.

~ Night Sky Network Telecon: Sue Ann Heatherly on the IBT ~

SARA received national publicity in the amateur astronomy community during a NASA Night Sky Network (NSN) Teleconference held on November 18, 2008. The program was on the radio sky and the "Itty Bitty Radio Telescope" (IBT). The featured speaker, Sue Ann Heatherly (Science Officer at The National Radio Astronomy Observatory, NRAO, Green Bank), mentioned SARA several times to the wide audience across the United States. She also talked about the IBT design by Kerry Smith, a member of the SARA Board.

SARA members in the audience included Tom Crowley, Kerry Smith, David Fields, John Mannone, Bill Seymour, Bill and Melinda Lord, and others. Strong local astronomy groups with which these persons are associated include The Atlanta Astronomy Club, Barnard Astronomical Society of Chattanooga, the SkyNet Observatory in Cleveland, TN, the TAOSON Group in Rockwood, TN, and the ORION Club in Oak Ridge. With nine or more persons involved, SARA may have had a greater participation in the teleconference than any other amateur astronomy organization.

You can download the excellent 13 MB PowerPoint from the NASA/JPL Night Sky Network site, http://nightsky.jpl.nasa.gov/docs/IBTcom1.ppt.

Bill Seymour, Associate Editor

~ New Members ~

Please welcome our new members who have joined SARA since the issuance of the last journal. (Please accept our apologies if your name is missing. If it is so, please see the administrative pages for the email address and send the information to the Treasurer (Melinda Lord) and to my Associate Editor (Bill Seymour). We will make sure it appears in the subsequent Journal issue). As of November 24, 2008, the new me members are:

First Name	Last Name	City	State	Country
Anja	Bloechi	Suenching	Bavaria	Germany
Richard	Castle	Hixson	TN	USA
William	Herzog, Jr.	West Chester	PA	USA
Ron	Olmstead	Marcellus	NY	USA
John	Roberts	Eugene	OR	USA
Frank A.	Rose	Lake Forest	CA	USA

Erratum in the Aug/Sep 2008 issue, misspelling corrected

Whitham D.	Reeve	Anchorage	AK	USA

~ Membership Dues ~

Membership dues are $20.00 US per year and all dues expire in June. Student memberships are $13.33 US per year. Members joining from June to December of 2008 will renew their membership June 2009. Members joining January to June 2009 will renew June 2010 (conference fees now include membership dues, see page 6).

Or pay once and never worry about missing your dues again with the SARA Life Membership. Sara Life Memberships are now offered for a one-time payment of twenty times the basic annual membership fee (currently $400 US).

Payment can be made on line at www.radio-astronomy.org with PayPal or mail check or money order to:

SARA
c/o Melinda Lord
354 N West Cir NW
Cleveland, TN 37312-1011
423-478-9043
treasurer@radio-astronomy.org

Melinda Lord, Treasurer

~ Radio Astronomy Resources ~

SARA
http://radio-astronomy.org

National Radio Astronomy Observatory
http://www.nrao.edu

SETI League
http://www.setileague.org

European Radio Astronomy Club
(Peter Wright)
http://www.eracnet.org/

Pisgah Astronomical Research Institute
(Don Cline)
http://www.pari.edu

Tamke-Allan Observatory
(David Fields)
http://www.roanestate.edu/obs

Deep Space Exploration Society
(Rex Craig/Jamie Riggs)
http://www.deep-space.org/

Jamesburg Earth Station volunteer group
http://www.jamesburgdish.org
http://www.bambi.net/jamesburg.html

Radio Sky Publishing
(Jim Sky)
http://www.radiosky.com

Radio Astronomy Supplies
(Jeffrey M. Lichtman)
http://www.radioastronomysupplies.com
jmlras@mindspring.com

RF Associates
(Richard Flagg)
1721-I Young Street
Honolulu, HI 96826
(808) 947-2546

RFSPACE, Inc.
(Pieter Ibelings)
Radio Astronomy Receivers)
http://www.rfspace.com
info@rfspace.com

Shirleys Bay Radio Astronomy Consortium
(Marcus D. Leech)
http://tech.groups.yahoo.com/group/sbrac-astronomy/
marcus@propulsionpolymers.com

GNU Radio
(Eric Blossom)
http://www.gnu.org/software/gnuradio/doc/exploring-gnuradio.html

Radio Astronomy Links
http://www.cv.nrao.edu/fits/www/yp_radio.html

~ The Spatial Filtering Effect of Radio Interferometers ~

By S. Kurtz (N9GKX) and D. Fields (N4HBO)

Abstract: *We discuss the origin and meaning of spatial filtering by interferometers, using the Very Large Array as an example. We demonstrate the effects of spatial filtering on a source with both small-scale and large-scale structures, and illustrate how to estimate the size sensitivity of an interferometer.*

If one hangs around radio interferometrists for a while, one is sure to hear the phrase "an interferometer is a spatial filter." But what does that mean? Even if one *doesn't* hang around with interferometrists, one may have wondered why it is that the Very Large Array (VLA), the powerful centimeter-wave radio interferometer operated by the National Radio Astronomy Observatory (Socorro, NM), has four distinct configurations. These configurations range from very compact (the D-configuration, or "D-array", with a maximum separation between antennas of about a kilometer), to very extended (the A-configuration, or "A-array", with a maximum separation between antennas of about 36 km). The array is cycled through these four configurations on a timescale of 16 months, spending about four months in each configuration.

Figure 1: North arm of the VLA, in the D-configuration (*Image courtesy of NRAO/AUI*)

The extended A-configuration offers the highest angular resolution, but in that case, why not *always* observe with the A-configuration? Isn't high angular resolution a good thing? Clearly, there must be some benefits to having the more compact configurations, or else the NRAO wouldn't spend the time, effort and money switching back and forth between them. But what precisely are the benefits of having both extended and compact configurations in an interferometer? The answer to this question is fundamental to the idea that interferometers are "spatial filters."

To understand what a spatial filter is, we first need to know what a spatial frequency is. After that, the "filter" part is easy – it's just something that accepts certain spatial frequencies while rejecting others.

When we talk about "frequency", we usually mean "temporal frequency" or "how many times per second" something happens. An obvious example would be a Radio Jove receiver operating at 20.1 MHz, where 20,100,000 wave crests arrive each second. Temporal frequency always has units of inverse time. Usually this is per second, or Hertz, but it can be a different unit, such as one paycheck per fortnight or 0.25 presidential elections per year. The temporal period is the inverse of the temporal frequency and tells us the length of time between events: 1/0.25 per year = 4 years between presidential elections.

But another form of frequency is "spatial frequency" where we specify "how many times in a given distance" something happens. Spatial frequency always has units of inverse length. Some everyday examples are (1) mileage markers, with a frequency of 10 markers per mile, (2) a vegetable garden, with three corn plants per foot of row, and (3) a millimeter-ruled meter stick, with 1000 marks per meter. The spatial period is the inverse of the spatial frequency, which tells us the physical distance between the events. So 1/10 per mile = 0.1 miles between markers.

To understand why these spatial frequencies are so important to an interferometer, we must realize that what interferometers measure (the so-called *visibility function*) is proportional to the Fourier components (http://en.wikipedia.org/wiki/Fourier_analysis) of the brightness pattern on the sky. If we measure enough of these Fourier components, we can construct an image of the sky brightness. Now here's the rub: *the Fourier components measured are not temporal frequency components, but rather are spatial frequency components.* The idea is to use sine and cosine functions to construct the image (via the Fourier technique), but instead of using the temporal functions $\sin\omega t$ or $\cos\omega t$, with ω as the angular frequency, we use the spatial functions $\sin kx$ or $\cos kx$, where k is the spatial frequency. To represent big shapes, we need low spatial frequency sinusoidal waves, while to represent small shapes, we need high spatial frequency sinusoidal waves.

With a radio interferometer, the low spatial frequencies are measured by antennas that are close-by to one another, while the high spatial frequencies are measured by antennas that are far apart. In particular, the angular size that is probed by an antenna spacing B, observing at a wavelength λ, is given by $\theta = \lambda/B$, where θ is measured in radians. Although λ and B can be measured in meters (or centimeters, or feet, or whatever, provided the same units are used for both quantities), it is advantageous to measure B in units of λ. So for example, if the wavelength of observation were 6 cm, then we would measure B in units of 6 cm. If the physical separation between two antennas were 30 meters, then B would be 30 m ÷ 0.06 m or 500λ. The advantage of these units is that λ cancels both above and below in the expression for θ. Thus, if the separation between antennas (which is called the *baseline length* in interferometry jargon) is 5 kλ, then the corresponding angular size is $\theta = 1/5000$ or 0.0002 radians or 0.7 arcminute. In general, a baseline $B = n\lambda$ allows the observation of sources with angular size n^{-1} radians.

Because any given arrangement of antennas in an interferometer will have only certain baseline lengths, only certain angular sizes can be detected. The interferometer can observe source sizes corresponding to the spatial frequencies for the baselines that are present, but the other spatial frequencies will be *filtered out*, because we have no way of measuring them without changing the spacings between the antenna pairs.

An audio analogy might be helpful. Imagine that we want to record a concert, but we have only one microphone to use, which has four frequency ranges: 50 – 200 Hz, 200 – 800 Hz, 800 – 3200 Hz, and 3200 – 12,800 Hz. There are a couple of things to note about our situation:

(1) There are some frequencies that we simply can't record. In particular, our microphone isn't sensitive to frequencies less than 50 Hz or greater than 12.8 kHz. They are simply lost to us; we have no way of detecting them. But as long as it isn't a pathological case (as with lots of bass drums and piccolos), we can probably still capture the essence of the music.

(2) If we want to make a faithful recording of the concert, we have to record it four times (once in each frequency range of our microphone) and then combine the four recordings.

The VLA is similar. Corresponding to the items above, we have:

(1) There are no antenna spacings shorter than 25 m (or the antennas would block each other; their diameter is 25 m). Likewise, there are no antenna spacings longer than 36 km, which is the physical extent of the array. Spacings shorter and longer simply aren't available. As long as the object we want to observe isn't really big (> 5 degrees) or really small (< 0.05 arcsecond), we should be able to make a reasonable image of it.

(2) But to make the best possible image, we have to observe the source four times, once in each array configuration, and then combine the results. In that way, we will include information on both large and small angular scales, with the large structures coming from the more compact arrays and the small structures coming from the more extended arrays.

The VLA is slightly more complicated than the concert analogy in the sense that to combine the observations they all have to be at the same wavelength. The extreme sizes of 5 degrees and 0.05 arcsec is cheating a bit, because the 5 degrees assumes we're observing at $\lambda = 400$ cm (where we can see larger objects; recall $\theta \sim \lambda/B$) while the 0.05

arcsec assumes we're observing at λ = 7 mm (where we can see smaller objects). This is because the interferometer has shorter baselines (which see bigger objects) if we measure in units of 400 cm rather than 7 mm. And vice versa, the interferometer has longer baselines (which see smaller objects) if we measure in units of 7 mm rather than 400 cm.

Changing the observing wavelength between configurations is something we wouldn't do in practice, because the object we're observing almost certainly has very different properties at different wavelengths. The proper way to calculate the range in sizes that an interferometer can observe is to compare the longest to the shortest baseline *for a given observing wavelength*. Independent of the observing wavelength, the longest VLA baseline (in A-array) is about 750 times longer than the shortest baseline (in D-array); hence, the VLA can detect objects about 750 times bigger than its basic angular resolution. That is, if the angular resolution (the smallest size we can observe) is θ arcsec, then the VLA can observe objects up to about 750θ arcsec in size. And we can do this only if we combine data from all four configurations. Within a single configuration, the ratio of the longest to the shortest baseline is about 40, so θ arcsec would be the smallest object and 40θ would be the largest object. Bigger objects will not be seen by the interferometer.

The observer's guide for the VLA (http://www.vla.nrao.edu/astro/guides/vlas/current/) has tables giving the range of baseline lengths, the angular resolution, and the largest possible structure that can be imaged by the VLA for each wavelength and each configuration. These tables are reproduced below.

Table 1: Max/Min Baseline Length

	A	B	C	D
Longest baseline (km)	**36.4**	**11.4**	**3.4**	**1.0**
Shortest baseline (m)	**680**	**210**	**35**	**35**

We see that A-array has the longest baseline, and also that its shortest baseline (of 680 m) is nearly as great as the *longest* baseline of 1000 m in D-array. The fact that C- and D-array both have the same shortest baseline is a recent innovation of the VLA. Although it is still called "C-array", it was (temporarily) called the "shortened-C" array. The VLA staff realized that if they would take several of the outer antennas (which provided longer baselines) and put them closer to the center of the array (at D-array positions) that they could have the best of both worlds: the angular resolution of C-array, but the sensitivity to large structures of D-array. We will see the effects of this in the next two tables. The immediate result is that C-array has a longer maximum baseline than D-array, but their minimum baseline is the same, with a separation of 35 m.

As explained above, because A-array has the largest antenna separations, it achieves the highest angular resolution, ranging from 24 arcsec at a wavelength of 400 cm to 50 milli-arcsec at a wavelength of 7 mm. D-array is at the other extreme, with about 30 times lower resolution. In fact, the antennas spacings increase by a factor of 3.125 (or about $\sqrt{10}$) between each configuration. Hence, if we change by two arrays (say from A to C) we will have about 10 times less resolution (in table 2 compare 24 to 260 for 400 cm; 6 to 56 for 90 cm, etc.). If we change by one more configuration to the D, we will have 10×3.125 or about 30 times less resolution (in table 2 compare 24 to 850 for 400 cm; 6 to 200 for 90 cm, etc.).

Table 2: Angular Resolution (in arcsec)

	A	B	C	D
400 cm	**24**	**80**	**260**	**850**
90	**6**	**17**	**56**	**200**
20	**1.4**	**3.9**	**12.5**	**44**
6	**0.4**	**1.2**	**3.9**	**14**
3.6	**0.24**	**0.7**	**2.3**	**8.4**
2	**0.14**	**0.4**	**1.2**	**3.9**
1.3	**0.08**	**0.3**	**0.9**	**2.8**
0.7	**0.05**	**0.15**	**0.47**	**1.5**

Because the D (and more recently the C) configuration has the shortest baseline, it is able to image the largest size objects. We see this in table 3, where the D and C configuration columns have the largest values. When we go to more extended configurations, we will reduce the largest angular size we can image roughly by a factor of 3.125 per array change – e.g., a factor of 10 when going from D-array to B-array. In table 3, compare 20,000 to 2,220 for 400 cm observing wavelength, or 4,200 to 540 for 90 cm observing wavelength.

Table 3: Largest Angular Size (arcsec)

	A	B	C	D
400 cm	**800**	**2,200**	**20,000**	**20,000**
90	**170**	**540**	**4,200**	**4,200**
20	**38**	**120**	**900**	**900**
6	**10**	**36**	**300**	**300**
3.6	**7**	**20**	**180**	**180**
2	**4**	**12**	**90**	**90**
1.3	**2**	**7**	**60**	**60**
0.7	**1.3**	**4.3**	**43**	**43**

To visualize these numbers, we show in the figure 3 below how the baseline lengths compare between the four VLA configurations. (Note that the figure is NOT to scale!) The D-array has the shortest baselines. The C-array has baselines just as short as the D-array, but also has some longer baselines. The B-array has some overlap with D and C, but goes to still longer baselines. Finally, the shortest A-array baselines coincide with the longest D-array baselines. There is some overlap with C- and B-arrays, but the longest A-array baselines are not present in any of the other configurations. Although the A-array has *a few* baselines, that overlap with the D- and C-arrays, there isn't enough overlap to be able to image large objects. The same is true with the B-array: although there is some overlap, there simply won't be enough low spatial frequencies observed to produce an image of a large object. To do that, we really must observe in C- or D-array.

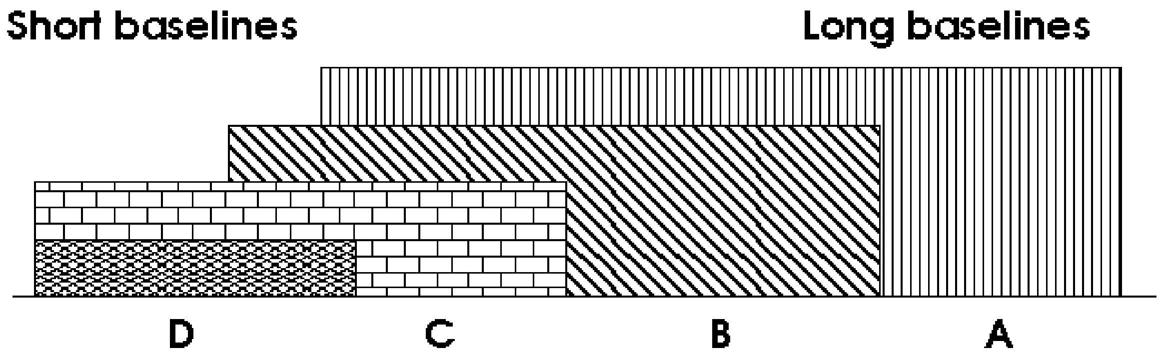

Figure 2: Baseline ranges of the four VLA configurations

The spacing between the VLA antennas is not uniform, but rather increases logarithmically along each of the three arms of the array. This is done intentionally, so as to provide a broader range of antenna spacings, and hence to sample a wider range of spatial frequencies. A simple case of this is to imagine that three antennas are placed along an east-west line. A poor way to place the antennas would be to place each one a distance *x* from the other (for example, antenna A at position 0 m, antenna B at position 50 m, and antenna C at position 100 m).

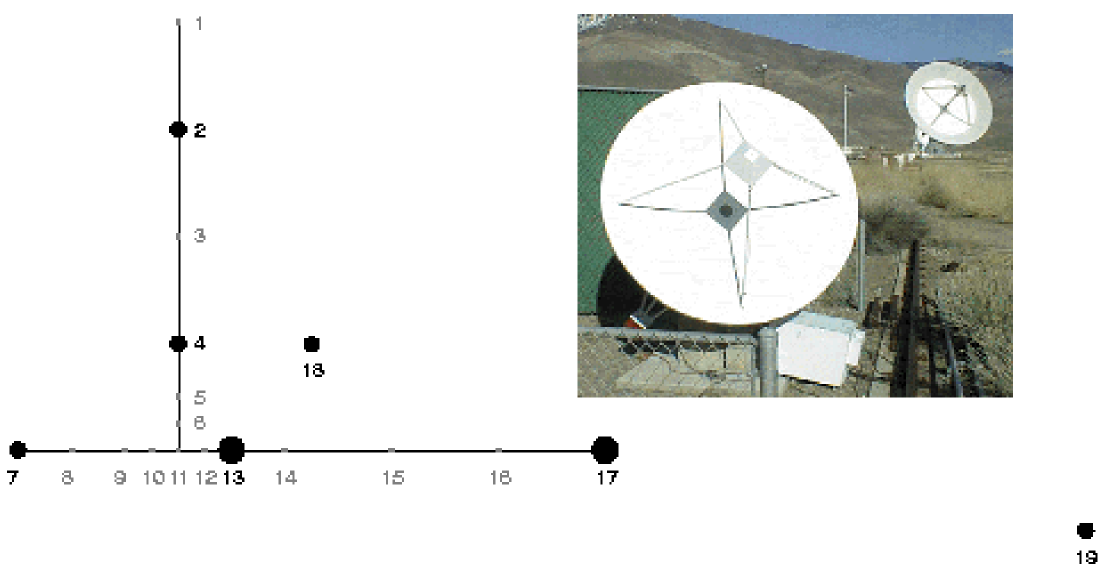

Figure 3: Possible antenna positions of the Owens Valley Solar Array (left) with a photo of two of the antennas (right) — the black dots indicate antennas positions; note how they are *not* uniformly spaced so that redundant baselines are avoided

In that case, our interferometer would have only two baseline lengths: 50 and 100 meters. The A-C pair would have a separation of 100 m while both the A-B and the B-C pairs would have separations of 50 m. The latter two baselines would measure the same spatial frequencies; they are *redundant* baselines. A better arrangement would be to put A at 0 m, B at 50 m, and C at 150 m. Then there would be three distinct separations: A-B with 50 m, B-C with 100 m, and A-C with 150 m. Hence, there would be three unique spatial frequencies measured and no redundant baselines. For the construction of the VLA and other interferometers, such as the Submillimeter Millimeter Array (SMA[1,2]) and the Atacama Large Millimeter Array (ALMA[3]), a great deal of thought has been put into optimizing the arrangement of the antennas to maximize the number of spatial frequencies that are observed. There are differing restrictions between arrays. For example, because the VLA antennas are moved using railway tracks, the antennas need to be arranged along straight lines. But ALMA will use a transporter that moves on roads, not rails, so the antennas are not constrained to be co-linear.

When one observes with an interferometer, it is actually the *projected* baseline length that matters. That is, the separation between the antennas *as seen from the astronomical object.* When the source is at transit, looking straight at the interferometer, the projected baselines are equal to the physical separation between the antennas. But at rising and setting, the source sees the array from the side, instead of straight on, so the separation between the antennas can appear to be much shorter. (Think of standing in front of the Lincoln Memorial. When looking straight at the building, the separation between the columns is large. But if you stand off to one side and look at the building from an angle, the columns appear to be much closer together.) These shorter projected baselines help considerably when making images with interferometers, because by observing at different times of day we can get different projected baseline lengths (and thus measure different spatial frequencies) without the need of physically changing the antenna locations. This is the principle behind *earth rotation synthesis telescopes.*[See aperture synthesis interferometry, http://en.wikipedia.org/wiki/Aperture_synthesis.]

To demonstrate the effect of incomplete sampling of spatial frequencies, we show a series of figures taken from some actual VLA observations. The figure 4 shows two images made with the VLA, both at a wavelength of 3.6 cm (or a frequency of 8.46 GHz). The image on the left, with the small, compact source, was taken in the B-array, while the very large HII region of the image on the right was observed with the D-array. The important point here is that the B-array data were taken *first.* At the time of the original publication of the data, we had no idea that the much larger region even existed! The reason, as we shall see below, is that the low spatial frequencies of the very large structure seen in D-array were not measured by the B-array – they were “filtered out”.

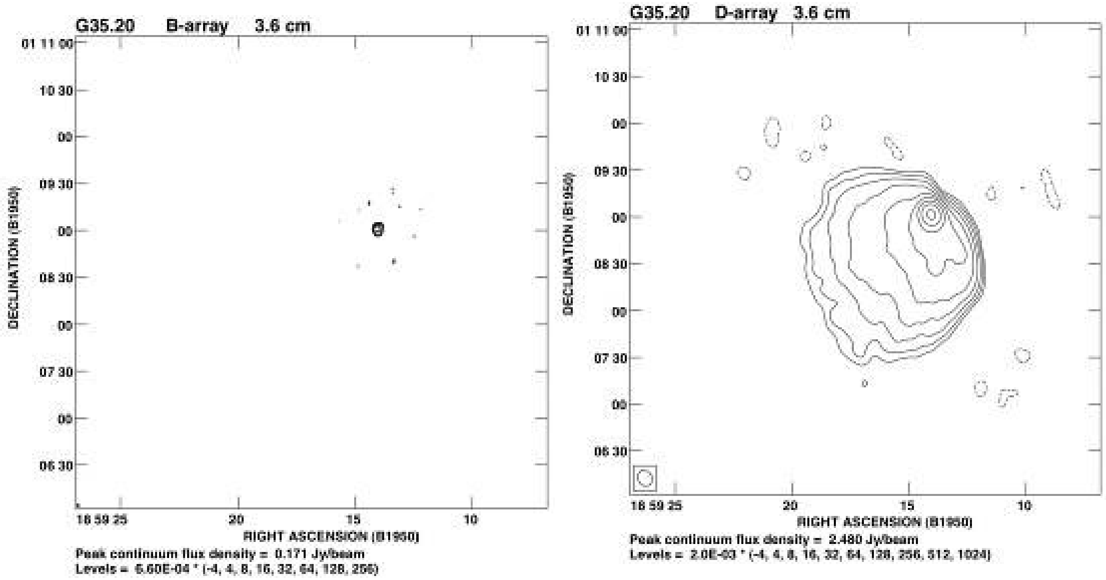

Figure 4: VLA image of the same sky region made with the B-array (left) and with the D-array (right).

To help you appreciate better the original observation, we show a "zoomed" view of it below, together with the later D-array image. The very compact structure seen in the original observation coincides with the dense peak of the much larger structure seen in the follow-up D-array observation. Internal structure is evident in both images, but at very different size scales.

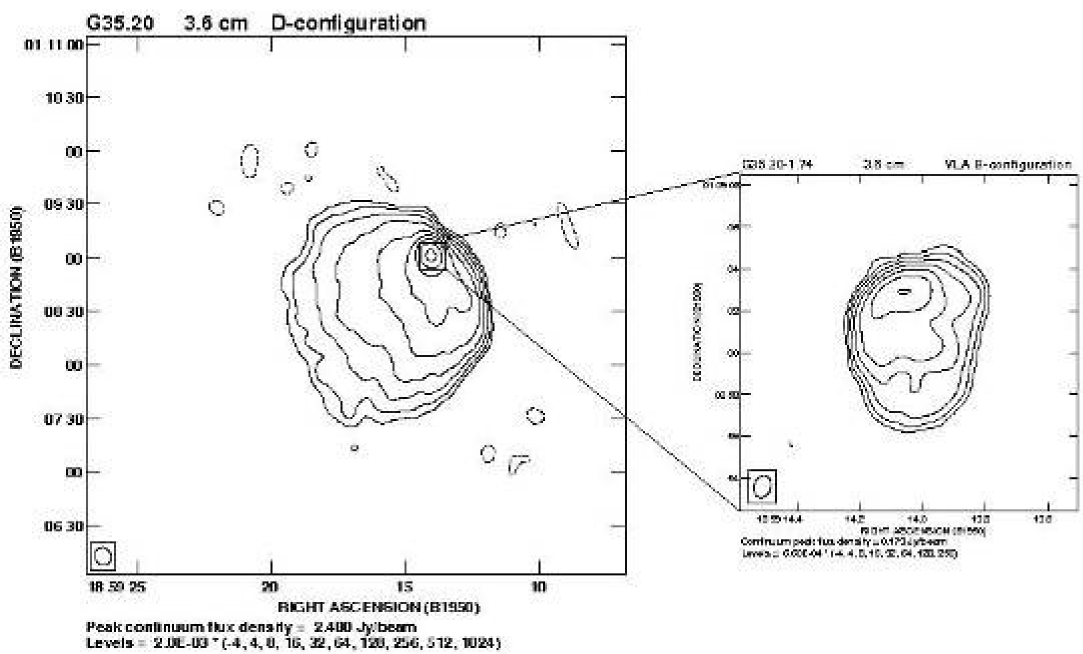

Figure 5: Zoomed in view of the B-array image (right), showing structure at arcsecond scales

The reason for the very different appearance of the two images can be understood by comparing the spatial scales in the images with the range of baselines present in each observation. The large HII region seen in D-array is about 110 arcsec in size. Converted to radians this is about 0.0000533, and taking the reciprocal, this corresponds to baselines of about 1.88 kλ. At a wavelength of 3.6 cm, this corresponds to 68 m. But according to table 1, the shortest baseline in B-array is 210 meters – so no data at 1.88 kλ were taken!

We can see this quite graphically in the figures below. Figures 6 and 7 show the so-called *uv-plane coverage* of the observations. This is a two-dimensional space corresponding to the Fourier components we are measuring. The points plotted indicate the separations between the antennas, measured in units of kilo-wavelengths, in addition to their angles projected onto the sky (i.e., east-west, north-south, etc.). The more points there are in these plots, and the more uniformly that these points cover the plane, the better we will be able to image the object, owing to better sampling of the Fourier components.

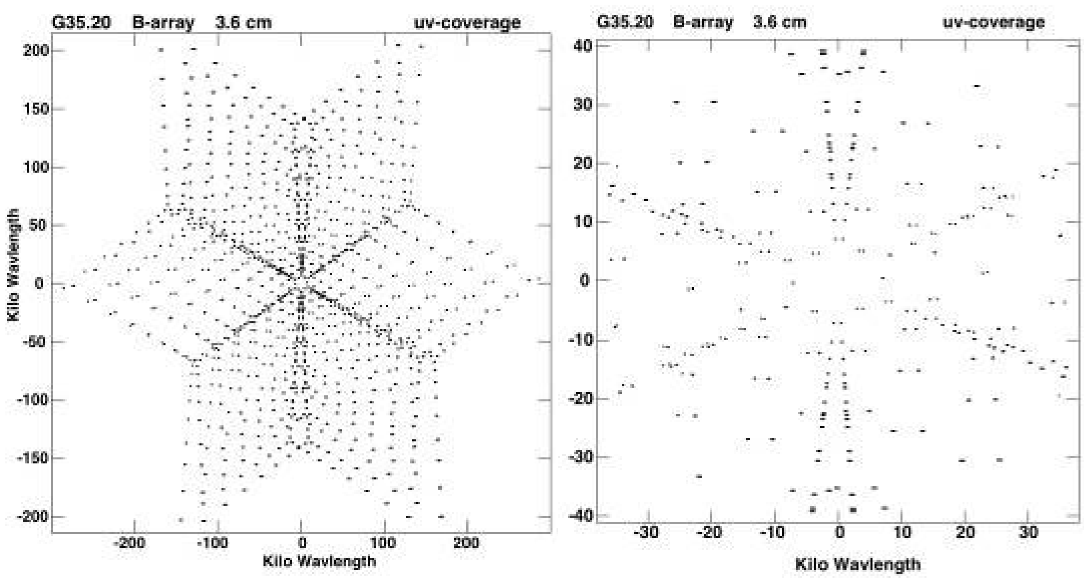

Figure 6: The *uv* coverage of the B-array, in which the original observations were made. Note that the largest antenna spacings seen on the left have a maximum extent of about 200 kλ. The star pattern results from two facts: (1) the three arms of the VLA, and (2) the fact that the uv-plane is Hermitian (and therefore symmetric). The right frame shows a zoom of the center-most region. Interferometers always have a hole at the center of these plots – this is the so-called *zero-spacing*, which must be provided by a single-dish telescope.

For the B-array data shown in figure 6, the maximum baseline is about 200 kλ, as indicated by the scales on the x and y axes of the plot on the left. On the right, we show a zoom of the center-most section, which shows a central hole whose size is about 5 kλ. No antennas in the array had such a short separation, so no data were taken for baselines shorter than 5 kλ. Note that 200/5 = 40, which as we noted above is the approximate range of baseline lengths in any given array configuration. The salient point here is that owing to the central hole, no data on baselines of about 1.88 kλ could be taken – such short baselines simply were not present in that VLA configuration.

Now we fast-forward about ten years, when suspicions started to arise that larger, more-extended structures might be present, surrounding the very compact emission imaged in the B-array. The same object was observed again, still at 3.6 cm wavelength, but now in the D-array. As can be seen from figure 7, the longest baselines now are about 20 kλ, and the central "hole" is about 0.5 kλ - i.e., both the longest baselines and the central hole are about ten times *smaller* than in the B-array. (Recall that between configurations there is a factor of 3.125 in size, so going from B to C to D there would be a change of 3.125 * 3.125 = 9.77.) Hence, we can image objects about ten times *bigger,* or up to about 410 arcsec in size. (As a check, we note 1/500 radians is 413 arcsec.) So in the D-array, the 110 arcsec HII region is easily visible – as the images above clearly show.

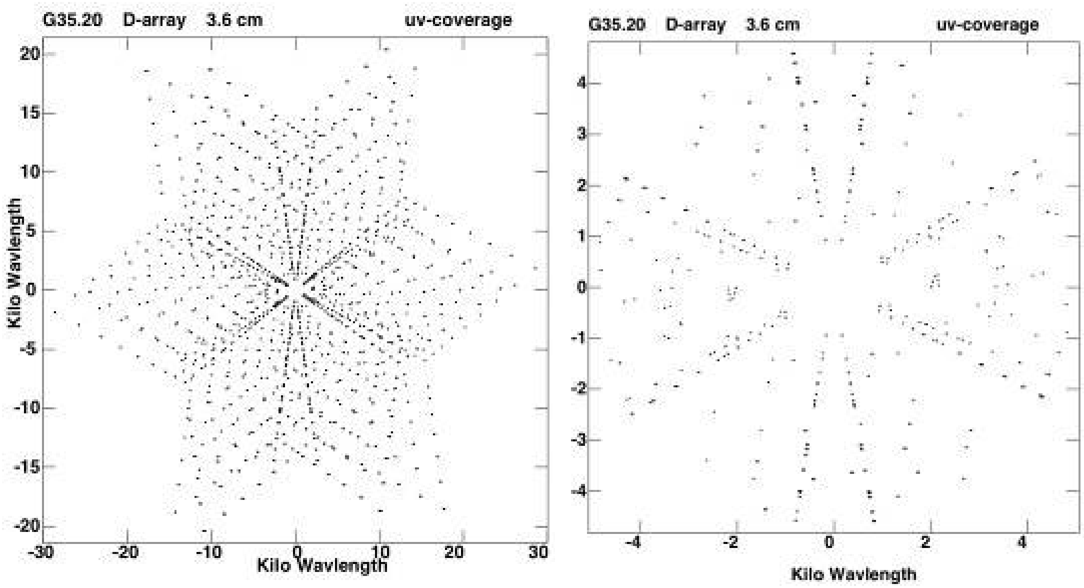

Figure 7: The *uv* coverage of the D-array, the most compact configuration available at the VLA. Note that the largest antenna spacings seen on the left fit within the very center of the corresponding plot from the B-array. The right frame shows a zoom of the center-most region, where it is noted that there are no antenna spacings less than about 0.5 kλ.

In figure 8, we show the flux density as a function of baseline length for both the B and D-array observations. When a particular baseline length has flux above the noise level, then that is a strong indication that there is emission on that size scale. So for example, on the left of the figure (for the B-array), we see a small "bump" in the flux density around 60 kλ, which corresponds to structures about 3.4 arcsec in size. This is roughly the size of the compact source that was observed in B-array. At even shorter baseline lengths, we see the flux density coming up sharply in B-array, reaching a level of about 300 mJy (or 0.3 Jy) on the shortest baselines of about 5 kλ. Comparing with the figure on the right, we see that the D-array flux picks up where the B-array left off. At 5 kλ there are about 0.3 Jy of flux, and it rises to over 1 Jy on the shortest baselines of 0.5 kλ. It's this extra flux, on the shortest baselines, that images the very large HII region seen in the figures above.

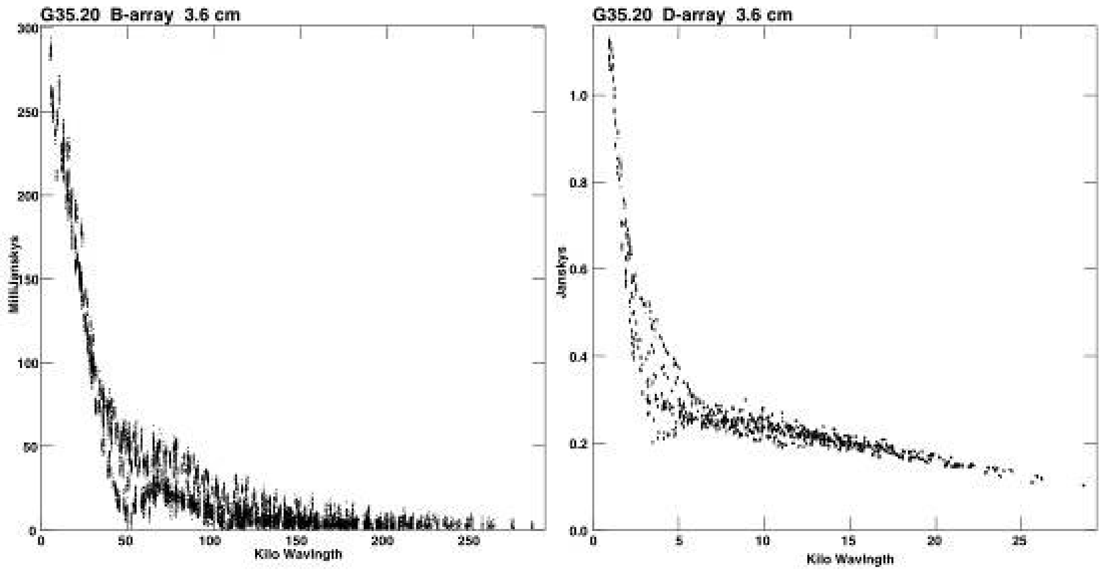

Figure 8: Flux densities from the same region of sky, as seen by the B-array (left) and the D-array (right)—the B-array flux scale is in milli-Jansky, while the D-array scale is in Jansky

In practice, when an astronomer wants to observe with the VLA, s/he needs to have a rough idea of the angular size of the object to be observed. It would make no sense, for example, to observe an object that is ten arcminutes in size with a frequency + configuration combination that can only image objects smaller than one arcminute.

Often the astronomer doesn't know before-hand just how big the object is. Usually one knows, however, if the source will be arcminutes or arcseconds in size. For example, planetary nebulae (PN) are almost always smaller than about 1 parsec (pc) in size (1 pc = 3.26 ly). In particular, if a PN is about 1 kpc away, then its angular size, θ, is estimated

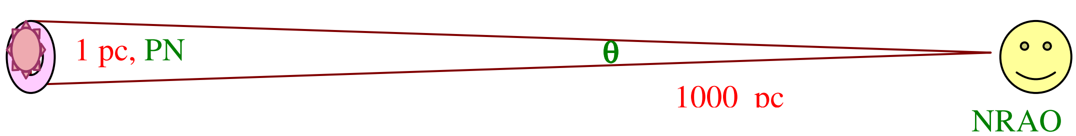

Figure 9: Geometry of observing a distant planetary nebula

by applying the central angle theorem: an segment of arc, Δs, with a radius of curvature, R, subtended by an increment of angle, Δθ, are related by, $\Delta s = R\Delta\theta$. Here, Δs represents the physical size of the planetary nebula and Δθ is its angular size.

$$\therefore \ \Delta\theta = \frac{\Delta s}{R} = \left[{}^{1\ pc}\!\!\diagup_{1000\ pc} \right]\left[{}^{180\ \deg}\!\!\diagup_{\pi\ rad} \right]\left[{}^{60\ arc\ \min}\!\!\diagup_{1\ \deg} \right] \text{ or 3.4 arcmin.}$$

If the distance is a bit uncertain (as distances often are), then we might build in a factor of 2 or 3 cushion, and say that the frequency + configuration combination should be able to image objects up to about 10 arcmin in size. If it turns out that the PN is a lot smaller, one can always ask for time to observe with a more extended array configuration.

Basically, if you know before-hand how big the object is, then you can plan very specifically for the observations. If you *don't* know how big it is, then you want to start out with the lowest angular resolution (and hence sensitivity to the largest possible structures) and move to higher resolution as needed. For the VLA, this means that you start out observing in the D-configuration, and then based on those results, you ask for time in the C, B or A-configurations. In particular, the Time Allocation Committee (TAC) considers it very reasonable if someone observes in D-array, detects an unresolved object, and then asks for more time on the grounds that higher resolution is needed. On the other hand, it is viewed very negatively by the TAC, if someone observes in the A-array and doesn't detect anything, and then asks for time in the D-array on the grounds that "maybe there really is something there, but we just couldn't see it because it was too big to be imaged by A-array." The statement may be true, but it's also possible that there simply isn't anything there. In the latter case, the astronomer would have wasted telescope time in both A *and* D-arrays. In the former case, only the time in D-array would have been used to show that nothing is there.

In summary, just as our artificial microphone could only record certain ranges of temporal frequencies, an interferometer can only detect certain ranges of spatial frequencies. This limits the size-scale of objects that can be seen by the interferometer. This can be both a blessing and a curse. If the object we want to observe is very small and is surrounded by big, bright objects, then we can make a better image by "filtering out" all of the bright, extended emission that doesn't interest us. But if we aren't careful, it can also act to hide important information about the source.

Very few amateur radio astronomers will have the luxury of so many antennas in their array that they can actually *image* the source. With just a few antennas, we are typically limited to measuring the fringe period and then calculating the size and position of the source [*See Lustrup's paper to follow— Editor*]. This is similar to the early days of radio interferometry when even NRAO, for example, only had three antennas in their array. Nevertheless, even for amateur interferometrists, it is important that the separation between antennas in their array correspond to the size of object to be observed. The Sun, for example, with an angular size of about half-degree, requires an antenna spacing of the order of 115λ at 500 MHz. For shorter spacings, it will appear as a point source and all that would be seen are fringes that help *locate* the source. However, to resolve the Sun fully, spacings somewhat greater than 115λ would be required. If we use very long spacings, say 1000λ (corresponding to an antenna separation of 600 m for an observing frequency of 500 MHz), then we would measure size scales of about 1/1000 radians = 0.06 degrees, and we wouldn't see the Sun at all!

Planning, proposing, and executing a research program on the VLA requires consideration of what one already knows about the source, in combination with the capabilities of the instrument in its various configurations. The VLA is a shared-use instrument, with many researchers competing for the limited time available. The actual time spent observing is almost always a very small fraction of the time spent preparing for the observing program, and afterwards, analyzing the data.

Amateur research with a smaller, amateur-built interferometer is similar, in that one must first decide what is to be studied, and then decide how to build and apply the instrument. The amateur, along with local collaborators, are likely to have their instrument available on nearly a full-time basis, but much of the available time will likely be a learning and "tweaking" experience - much more so than for a VLA researcher who arrives at the site with a pre-planned observational program, and expects the instrument to work "without a hitch." In the case of the VLA, hundreds of thousands of person-hours have been dedicated to producing an instrument that is sufficiently robust and reliable that the visiting astronomer can take for granted that it will work flawlessly.

Footnotes

[1] http://smadata.cfa.harvard.edu/sciDoc/
[2] http://sma-www.cfa.harvard.edu/sciDoc/Ho.pdf
[3] http://www.nrao.edu/index.php/about/facilities/alma/

Editor's Note: Though advanced, New Jersey's Science and Technology University (NJIT) has a freely accessible online course, Radio Astronomy. See Lecture 6, Fourier Synthesis Imaging. It has some very useful graphics, http://web.njit.edu/~gary/728/. In addition, see the Virtual Radio Interferometer, a Java simulation, http://www.jb.man.ac.uk/vri/vri/guide.html,

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Dr. Stan Kurtz is a physicist (University of Wisconsin) turned radio astronomer. His research has taken him to the Arecibo radio astronomy facility and more recently, to the Very Large Array. His current research is performed primarily at the Very Large Array where he serves on the VLA user scheduling committee. Stan is a member of the graduate faculty of the Center for Radioastronomy and Astrophysics of the National Autonomous University of Mexico, located in Morelia, Michoacán, Mexico. He contributed presentations to SARA annual and regional conferences. Since Stan suffers from abject modesty, this bio was prepared by his co-author.

Dr. David Fields is also a physicist who enjoys teaching, (amateur) optical and radio astronomy, and occasionally flying and diving. Like Stan, who is surely much older, David did his graduate work (Solid State Physics) at the University of Wisconsin and has his ham license. He has developed and applied computer models of environmental radionuclide transport and projected risk. David frequently presents at the SARA Green Bank conference, serves on the SARA board, and is observatory director of a small secret observatory in East Tennessee (visitors welcome -- see www.roanestate.edu/obs).
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~ 4-GHz C-Band Interferometer Project ~

By Jan Lustrup, LA3EQ

While surfing the internet, I found Marko Cebokli's interesting article on a homemade interferometer, http://lea.hamradio.si/~s57uuu/astro/sidi1/sidi10.htm called the SImple Digital Interferometer (SIDI),. Intrigued by the ability of recording solar fringes with the use of only two small short backfire antennas (a dipole, sub reflector and a "cake pan" main reflector!), I had to try to make an interferometer for my self to see these fringes. I built one with my own design using two 4 x 4 Quad loop element antenna in front of a reflector plane, two 1-GHz band pass filters, two *Minikit* low noise preamps (0.35 dB NF), several inline satellite TV amps and a triple diode balanced mixer. I tried to detect extragalactic sources on 1 GHz for a few weeks with no success, not even a single sun fringe. I found this frequency band to be too polluted with man made signals (airplane transponders, cell phones and UHF TV transmitter harmonics etc.) to be useful for any weak signal L-band radio astronomy in the city. A check of my HP spectrum analyzer showed a lot noise from HF to well above 2.6 GHz. So I needed to go even higher in frequency. Above 3 GHz, the terrestrial noise level should be lower. I googled "C-band interferometer" and found an interesting paper by Ken Tapping titled, *Radio Astronomy Experiments at 4 GHz*, I quickly made my own block diagram (figure 1) and obtained needed parts for this new project. I already had the mixers, line amps, band pass filters, coaxial cables/connectors and a nice 5170 MHz high level PLL Local Oscillator, but I still needed two C-band LNB's to complete this project.
http://www.ukaranet.org.uk/projects/Radio_Astronomy_Experiments_at_4_GHz.pdf

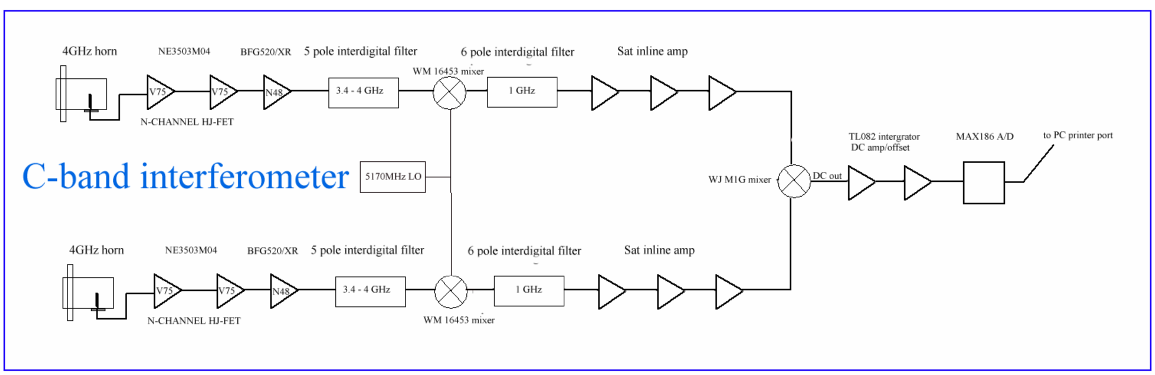


Figure 1: Block diagram for my C-Band interferometer

I saw an ad on E-Bay for a super low noise C-Band LNB (figure 2) selling for $12.95 each, so I ordered two of them. The low noise figure claimed is 0.2 dB (13K) and the accessible lid screws for ease of modification made them very tempting to buy.

These C-band LNB units have 13K noise figures, horizontal and vertical polarization, RF input frequencies of 3.4 to 4.2 GHz, a 5150 MHz LO, an output IF from 950 MHz to 1750 MHz, and have a 55 dB conversion gain factor. Scalar rings are included.

Having checked the 3.4 to 4.5 GHz frequency band with my HP 8565A spectrum analyzer, it was almost "clean as a whistle." Only two remote telecommunications carriers, well outside my 30 MHz IF band pass, centered around 3.6 GHz. Things were looking promising for a change. The LNB showed a solid 5 dB of ground noise over quite sky, around 1 dB of sun noise (but no moon noise) and I got to play around with the scalar rings for the first time, too. These rings make a big difference in sky-to-ground noise ratio. When one is placed in front of a 1-meter dish, it minimizes spill over and lowers ground noise. The LNB showed a nice solar transit. I clearly could see an indicated variable signal sky-to-ground level when changing the scalar rings position. I then assembled everything and interconnected both onboard mixers with one common 12-foot coax link.

Figure 2: Bargain e-bay C-Band LNB


Figure 3: Unmodified C-Band LNB (DRO lid and housing removed)

By using this interconnecting coax, I hoped the two onboard oscillators might oscillate in phase. But the built-in mixers did not oscillate coherently, they where living their own life independently! So I removed the dielectric resonators in the two DROs and put a microwave mixer outside each LNB (figures 3 and 4). I kept the DRO mixer/oscillator transistor. And I used it as the last RF amp in the RF chain for added gain to the mixer. Then I drilled two holes in the casing and used half a 30-cm length of RG142/u with ready-made SMA connectors in the ends. One LNB self oscillated, so I had to add extra screening (a strip of thin copper) between the RF side and the mixer/IF side.

The two ends were soldered to the DRO oscillator transistor's output. I soldered the other coaxial cable to the IF tap coming from the DRO mixer. Then I built a homebrew T-divider using three SMA connectors to split the JWM 5170 MHz Phase Locked Loop Local Oscillator (PLL LO) into two 16-foot lengths of RG143/u to feed each mixer in each LNB. (Normally, I use this LO unit for the 10 GHz transverter with a 28 MHz radio as IF.)

Figure 4: Modified LNB with outboard mixer

You will find more information on the details of my modifications at my homepage, http://home.no.net/jhhl/egne/LNB.html

Figure 5: The 5170 MHz PLL LO with impressive +7dBm output

Figure 6: Ready to go C-band LNB unit

Now I have a *30 MHz @ -3dB* slice at 4 GHz in two channels to play with. I then mounted the two LNBs (no dishes) in each corner of my porch, pointing to the southern celestial meridian and 45 degrees upward from the horizon, which means they were only 7 feet apart. First light gave fringes right away. But it turned out to be noise from my lap top PC power unit, since the noise fringes disappeared when I switched to battery mode.

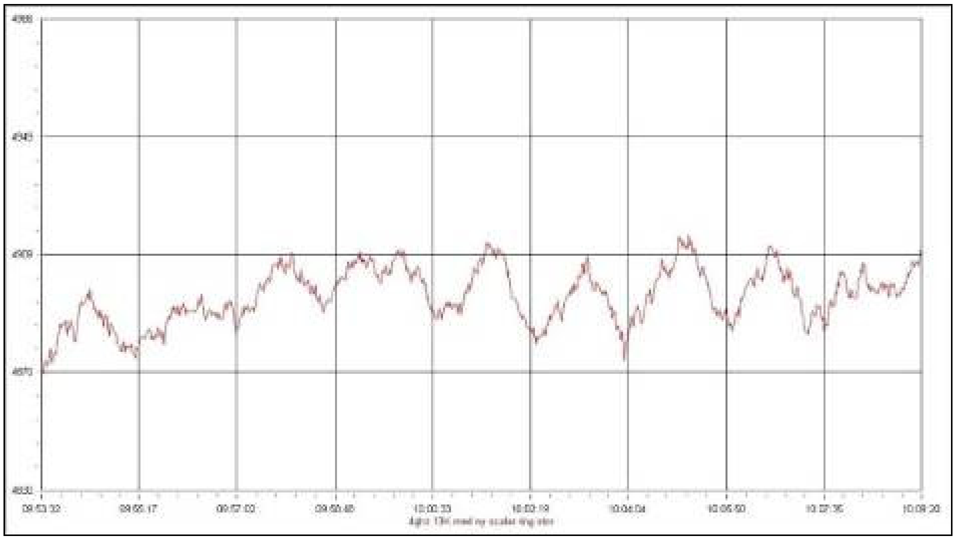
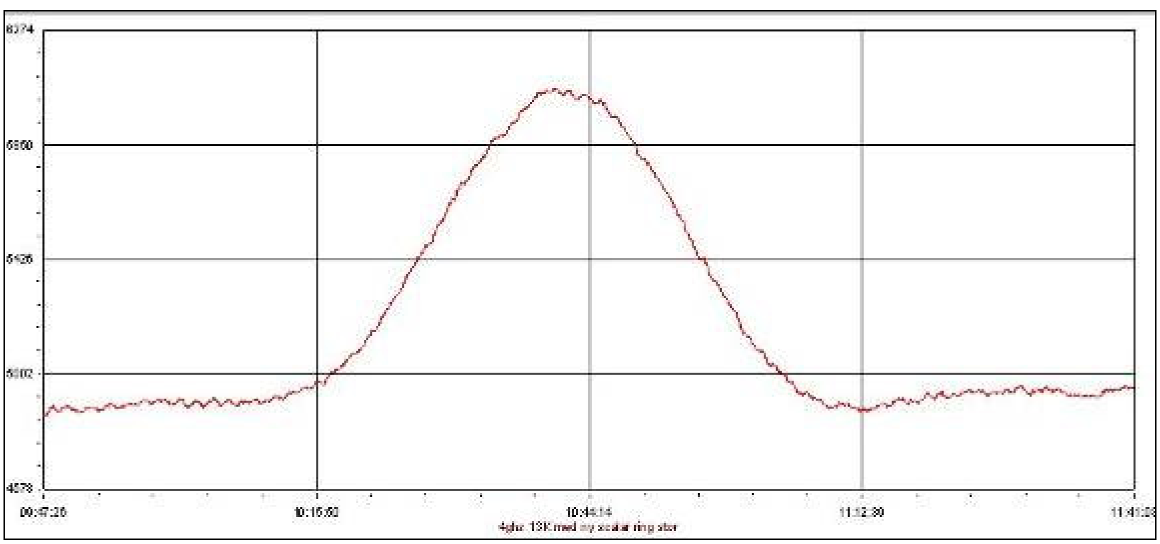


Figure 7: First light signals contaminated with switch-mode Laptop power noise (logged with Radio-SkyPipe sold by Jim Sky)

The next day I set up a single dish to get a solar transit to check out the system sensitivity for each antenna.



Figures 8: Single-dish solar transit

Next, I connected the two dishes together: the left dish with a 100 cm offset, the right dish with an 80 cm offset. I then lined up the antennas in a 2-meter east/west baseline configuration using the scalar ring's leading edge as reference points.

Figure 9: The two-dish (1 meter) interferometer (seen with common 5170 MHz LO feed)

Back indoors, I had a hard time trying to adjust the DC offset and gain control and the DC amplifier gain feeding my ADC, since the signal was way off scale and changing up and down repeatedly. Little did I know at the time that the strong fringes from the sun where causing these level changes. I wasted a lot of time chasing the DC level to get it right, but finally I got the signals inside the max/min chart screen boundaries. The sun had now drifted way out of my main lobes, so I pointed the antennas a little ahead of the sun, ready to see the sun fringes again. And there they were, just as one would see in the textbooks!

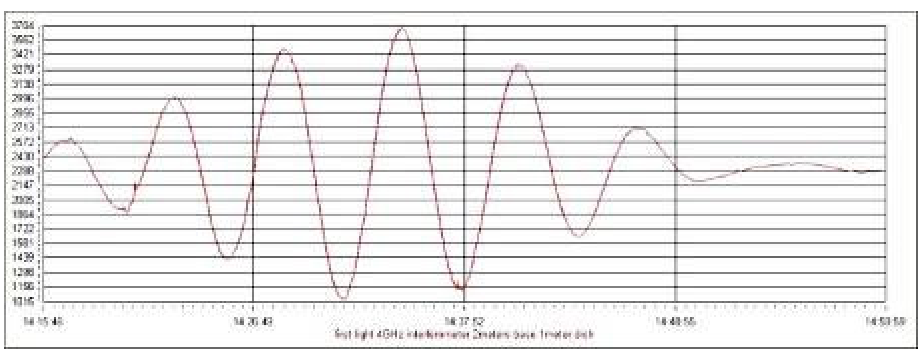
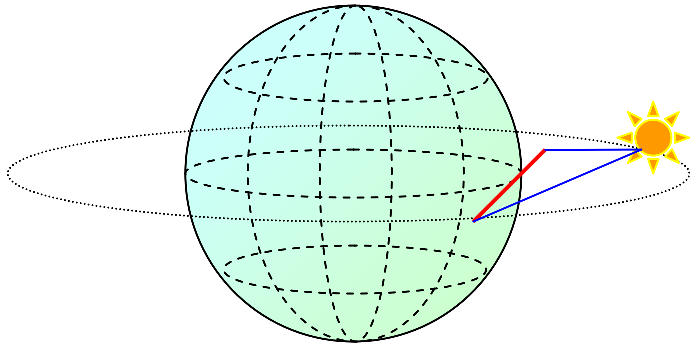
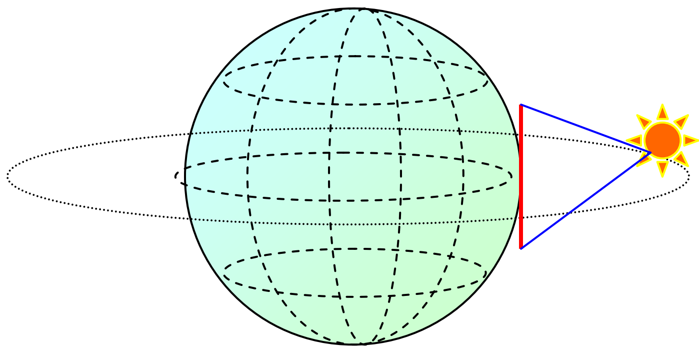


Figure 10: First light Sun fringes with a 2-meter baseline

Orientation along an east-west baseline is important. The “cartoon” below shows a simplified model (earth’s spin axis perpendicular to the equatorial plane). Figure 11 shows a 2-element interferometer set-up on the equator targeting the sun. To obtain fringes, the radio waves must arrive at the two antennas (one on each end of the red bar) at different times. The perspective of the baseline from the point of view of the Sun changes continuously, so a fringe pattern will be seen that is symmetrical and the more baseline, the fringes will ride the solar curve, as shown in figure 12.



a. East-West baseline in idealized system with no tilt to spin axis: Projected baseline varies as Sun moves across the sky resulting in fringes at the equator



b. North-South baseline in idealized system with no tilt to spin axis: Projected baseline appears the same as Sun moves across the sky resulting in no fringes at the equator

Figure 11: Earth/Sun system, 2-element interferometer (baseline in red), light rays (blue, perpendicular to wave front)

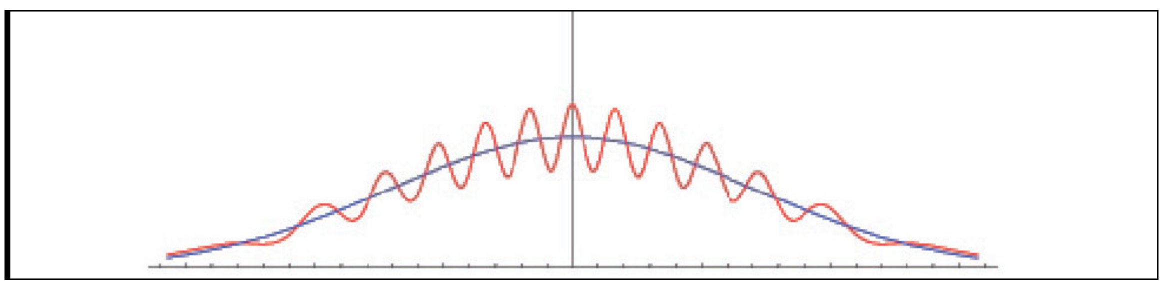


Figure 12: Fringes riding on solar intensity curve

Care must be taken when configuring the interferometer. Otherwise, the curve will not be symmetrical and corrections to obtain quantitative results would be non-trivial.

In the recordings, which I also made with 6-meter and 9-meter baselines later, the fringe patterns were not "like the ones in a textbook" because I was still learning what was important in interferometry. The high attenuation due to the long lengths of coaxial cable (UT141) for the common LO at the 9 meters baseline, resulted in very low LO injection level at the LNB's outboard mixers, so that is why the recording looks a little fuzzy. The rise and fall of zero crossing line could be due to none linearity in the mixer diodes, but I am not sure at this time.

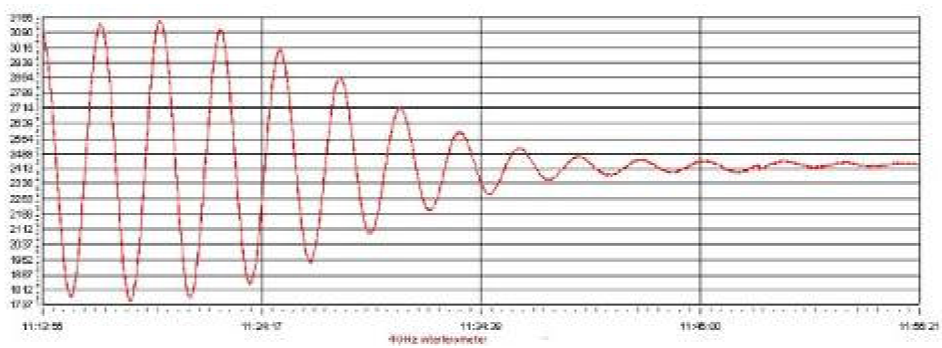


Figure 13: Solar fringes with a 6-meter baseline

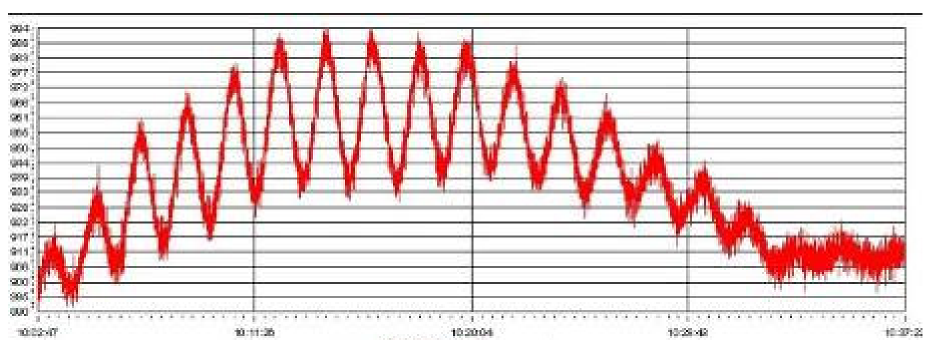


Figure 14: Solar fringes with a 9-meter baseline

Though these results are qualitative, they demonstrate the interferometer is working. Later, careful measurements are made with improved electronics. It was not known at the time, but the integrator introduced noise, as well did some carbon resistors. The chips used are not stable against thermal drift.

These later tests are included now to shown the interferometer is accurate and precise. Depending on how the fringe period is extracted from the interferogram (figure 15), results will vary. Here, we get a declination of 19.0 ° ± 1.6 ° (see below for a similar calculation). Figure 16 shows the expected declination. The accuracy error and the relative error are each around 8%.

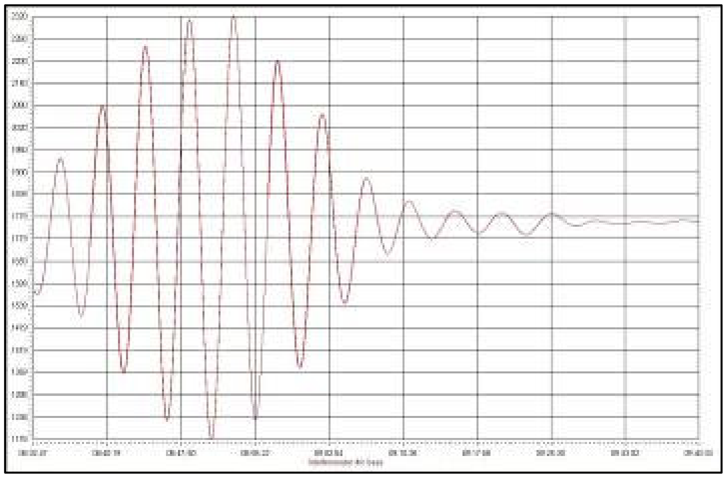


Figure 15: Solar fringes with a 4-meter baseline

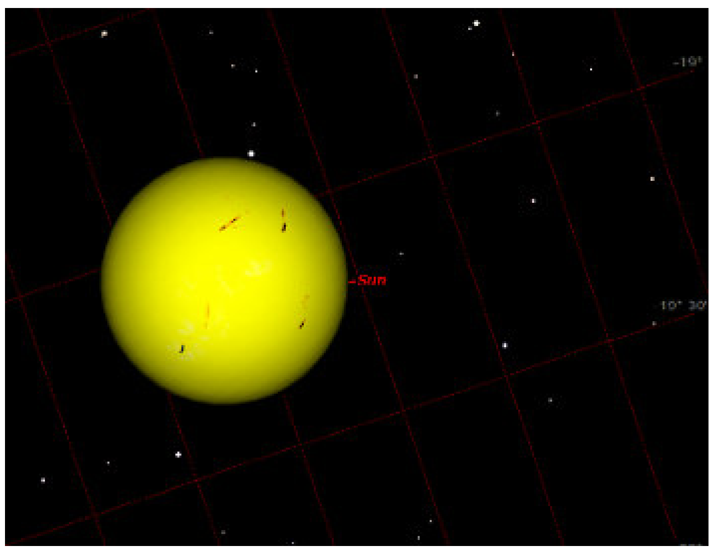


Figure 16: Starry Night shows solar declination at 19.1°
Stavanger, Norway Nov 17, 2008, 8:49Z (144 Az, 6 Alt)

In the evening, when I tried to look at weaker targets, I adjusted the gain up a bit, and I replaced the 1 μF capacitor in the integrator with 180 μF. This turned out to be too large. A 47 μF or 100 μF capacitor is more than enough with the 1 MΩ resistor in my R/C integrator.

Since this was a proof-of-principle experiment, these first measurements were semi-quantitative. On retrospect, the baseline was about 2 and 1/4 meter from LNB to LNB and one dish was behind the other, perhaps, maybe 10 cm or so. I then elevated the antennas upward almost to zenith and made a new recording (figure 17). At around 01:30 UTC (August 16, 2008), I noticed some fringes (see figure 13), but I did not know what to make of it yet. This recording showed three fringes evenly spaced and centered at 01:30:32 UTC, this might be “Cassiopeia A”, since the antennas were pointing in that direction. Radio source movement produces fringes due to a phase difference when the same signal travels at two separate distances when reaching each antenna, but this does not happen when the signal is in dead center of both antenna boar sites. Here signal levels multiply in the multiplying-correlator and produce its maximum signal amplitude at the point at equal phase. To find out if this source really is “Cassiopeia A” I had to do some calculations first. I found some information about fringes at Fringe Dwellers home site http://fringes.com. Steve McCauley and Marko Cebokli helped me by email on how to calculate fringes.

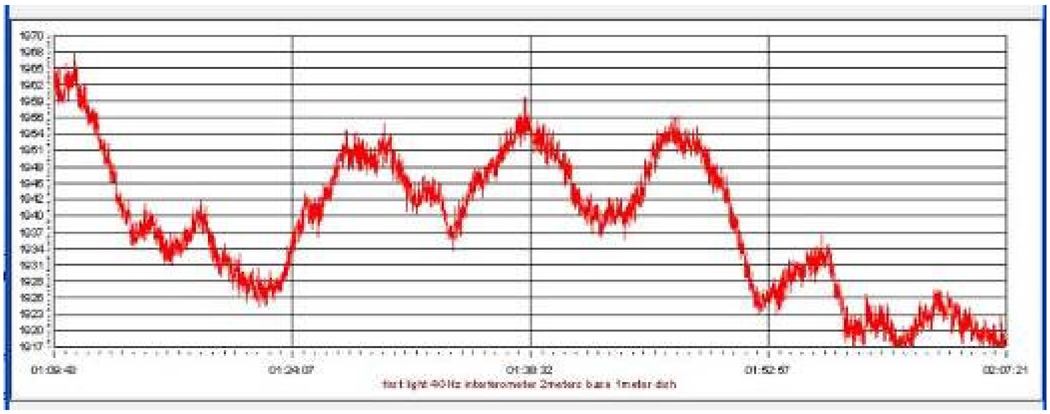


Figure 17: What radio target is this unknown signal?

Usually you need to find out one of two things: the fringe period or the source declination. The fringe period (T) is the time (usually in minutes) from the fringe top to the fringe top, or the time period from the first fringe zero crossing to the third zero crossing (this will give you more accuracy). The source declination (δ) is degrees above (+) or below (-) the celestial equator line. For a source on the celestial equator, you get the equatorial fringe period ($T_{equatorial}$) regardless of your position on the Earth. For a source at the celestial pole, you get no fringes at all (the rate is zero, the period is infinite), because the distance between your antennas and the source does not change. The source fringe period is shortest (or has its highest rate) on the celestial equator ($\delta = 0$) and grows progressively longer (lower rate) for sources above or below this position.

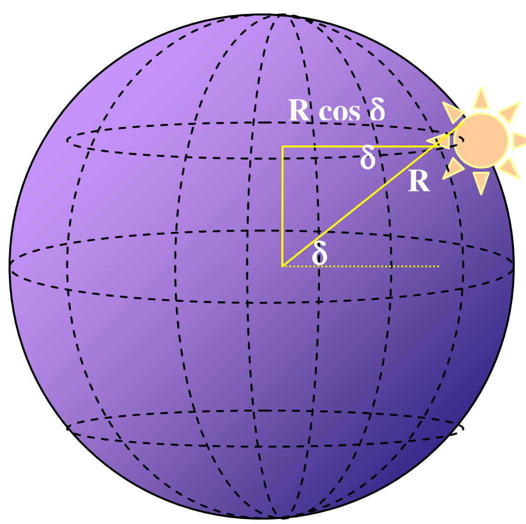


Figure 18: Celestial Sphere rotating at angular speed ω sweeping radio target at declination δ

From the geometry of incoming waves to two antennas, the baseline is related to the radio wave characteristics and the fringe periods at two different locations (the equator and from where the measurements are made). Equation 1 is really the diffraction equation.

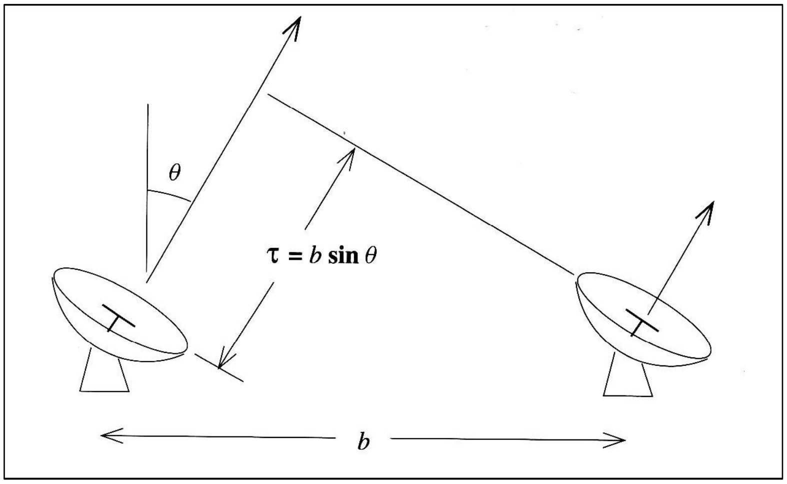


Figure 19: A drawing of a two-element interferometer shows the geometrical time delay, τ, resulting from radio waves arriving at antennas at slightly different times. Compensation for this delay is usually done electronically corresponding to an offsetting instrumental time delay (cited from Burke & Graham-Smith 2002). Note that θ is complementary angle of δ => sin θ = cos δ

$$D = \frac{\lambda}{\cos\delta \sin \omega_{earth} T} \approx \frac{\lambda}{(\cos\delta)(\omega_{earth} T)} \Rightarrow$$

$$T\cos\delta = const \quad T_{equatorial}\cos 0 = T_{observation}\cos\delta$$

Equation 1a

$$\therefore \cos\delta = \frac{T_{equatorial}}{T}$$

Equation 1b

To find out which target the fringes (figure 17) correspond to, methodically proceed through the calculations below, which are based on a frequency of 4112 MHz and an east/west baseline of 2.25 meters.

The baseline is imprecise and is estimated, fringe spacing at the celestial equator is,

$$fringe\ spacing = \frac{wavelength}{base\ line}$$

$$fringe\ spacing = \frac{0.073\,m}{2.25\,m} = 0.0324\ radian \frac{180°}{\pi\ radians} = 1.86°$$

Equation 2

The equatorial fringe period follows from equation 2 and the fact that earth rotates on its axis at 15 degrees per hour or 0.25 degrees per minute,

$$equatorial\ \ fringe\ \ period = \frac{fringe\ spacing}{earth\ rotation\ rate}$$

$$equatorial\ \ fringe\ \ period = \frac{1.86°}{0.25°/\min} = 7.44\ \min$$

Equation 3

From figure 17, estimate the source period. Looking at the 1st, 2nd and 3rd central fringes, the average of the two periods is 14.5 divisions (with a minimum uncertainty of one division of time). A close inspection shows 21 divisions correspond to 14 minutes 25 seconds (or 14.4166 minutes); therefore, the source period from the experimental data is,

$$source\ period = \frac{14.5 \pm 1.0\ div}{21.0\ div \big/ 14.4166\ \min} = 9.95 \pm 0.69\ \min$$

Equation 4

Now, apply the results from equation 4 to equation 1, the source declination (within 4 or 5 degrees),

$$\cos\delta = \frac{T_{equatorial}}{T} = \frac{7.44}{9.95 \pm 0.69}$$

$$\therefore\ \ \delta = 41.7°$$

Equation 5

The cosine function is sensitive to small changes in the source period, but this semi-quantitative result shows that Cygnus A is the likely candidate, since the experimental result falls within an interval containing the declination for Cygnus A (+40.73°).

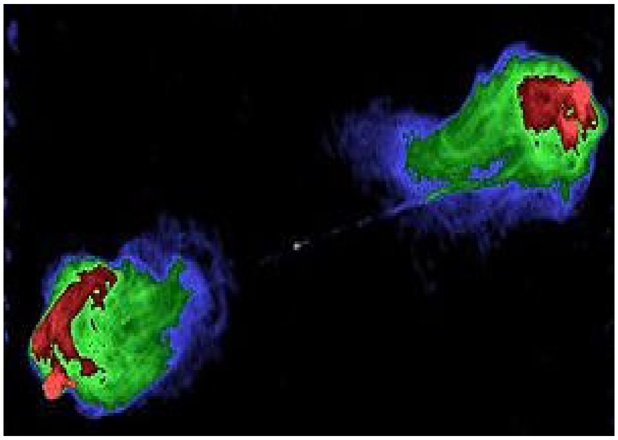


Figure 19: Cygnus A (3C 405) is one of the brightest and most famous radio galaxies — discovered by Grote Reber in 1939

Observation data (J2000 epoch)
Constellation Cygnus
Right ascension 19h 59m 28.3566s
Declination +40° 44′ 02.096″
Distance 600 Mly
Apparent dimensions (V) 0.549' × 0.457'
Apparent magnitude (V) 16.22
(*NASA/IPAC Extragalactic Database*, http://nedwww.ipac.caltech.edu/)

A more recent attempt to capture Cassiopeia A was successful. With the dishes configured 4 meters apart and pointing straight up, 8-minute fringes were indeed observed. As can be seen by modifying the calculations in equations 1-5 (fringe spacing 1.054 degrees, fringe period 4.18 minutes, source period 8 minutes), the declination (inverse cosine of 4.18/8.00) is found to be +58.5°, which agrees well with +58.8°. It is noteworthy that RadioEyes has a utility to compute fringe spacing. It predicts an 8-minute source period for the 4 meter baseline (for the 2-meter baseline, period would be 16 minutes).

Figure 20: Cassiopeia A detected: Fringe pattern with a 4-meter base line

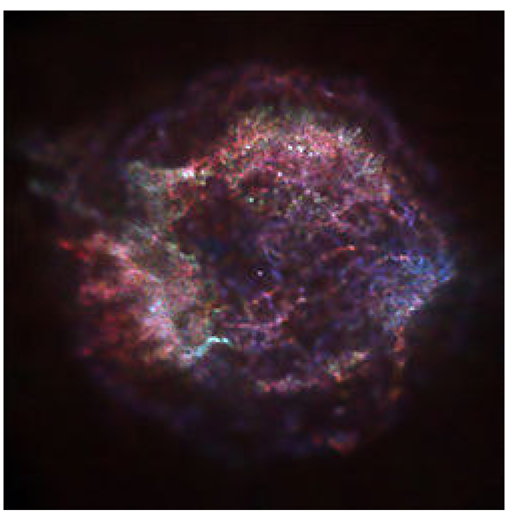


Figure 21: Cassiopeia A

Observation data (Epoch J2000)
Supernova type IIb
Remnant type Shell
Host Galaxy Milky Way
Constellation Cassiopeia
Right ascension 23h 23m 26s
Declination +58° 48′
Discovery Date 1947
Peak magnitude (V) 6?
Distance 11 kly (3.4 kpc)
(*NASA/IPAC Extragalactic Database,* http://nedwww.ipac.caltech.edu/)

Results

Solar fringes, as well as those for Cygnus A and Cassiopeia A, have been successfully identified with this 4 GHz interferometer. Despite initial experimental uncertainties in the fringe period because of the noisy signal, the zero line crossings or peak-to-peak measurements were sufficiently precise to render an accurate determination of the galactic targets. These strong sources are well within the capability of most C-band radio telescopes; their strength can be seen in the modified radio spectra below (source unknown, possibly reproduced from John Kraus' book in the NRAO Library at Green Bank, WV), http://home.earthlink.net/~jcmannone/.

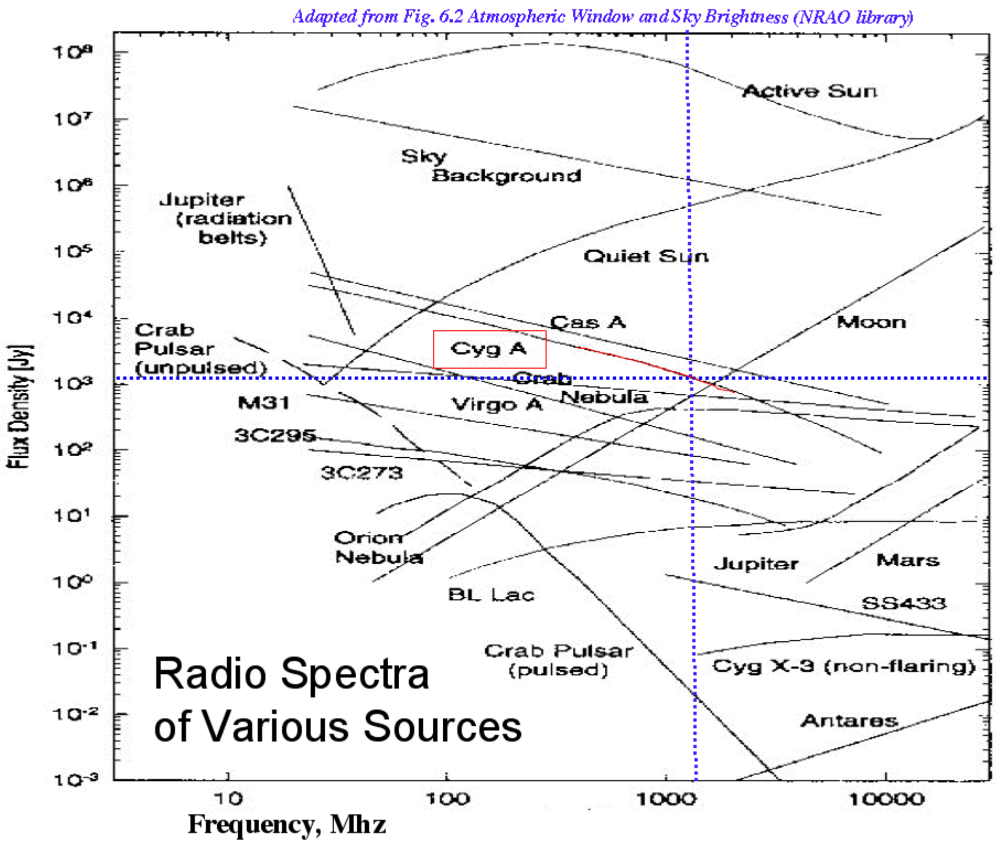


Figure 22: Radio spectra radio brightness (Jy) as a function frequency (MHz) for various radio targets — C-band flux densities are slightly lower than the depicted L-band levels for Cygnus A and "nearby" Cassiopeia A

I found a noise source within my integrator/offset amplifier system—cheap carbon resistors are noisy! I exchanged the two that where in series with my multi-turn resistor with metal oxide ones. I got much less noise. I also found the source of drift. My IC amplifier (TL 082) is temperature sensitive. I disconnected both inputs from the antennas and grounded the input to the op-amps, then recording for 24 hours. It showed typical drift. When I put my finger on the IC, the chart started moving upwards. The next thing I will do is try to buy some low noise temperature stable IC's by mounting them on a big aluminium block and placing them in a Styrofoam box and see if I get a nice and level chart recording with the input still grounded.

Editor's Note: Complementary figures and assistance with the analysis of the Cygnus A fringe pattern supplements this work.

Sidebar on Local Sidereal Time (LST): LST is the most useful form of sidereal time since it gives the right ascension of a transiting celestial object at a given location. To compute the current local sidereal time LST, consult the current Astronomical Almanac. Look up the "G. Sidereal Time (Apparent)" GST at midnight (0 h) in the third column corresponding to the current date universal time. Let T be the current local 24-hour time, and add hours to convert from local time to Greenwich Mean Time. Cited from Wolfram Research)

Duffett-Smith, P. "Local Sidereal Time (LST)." §14 in Practical Astronomy with Your Calculator, 3rd ed. Cambridge, England: Cambridge University Press, p. 20, 1992.

United States Government Printing Office. The Astronomical Almanac for the Year 2000. Washington, DC: Navy Dept., Naval Observatory, Nautical Almanac Office, pp. B4-B15, 2000.

However, a Java applet, http://tycho.usno.navy.mil/sidereal.html, allows the calculation of local apparent sidereal time LST from the longitude. For the coordinates of Stavanger, Norway — Lat 58° 58' 38" N, Lon 5° 43' 39" E — **LST is 10:36:51.3**

Also useful in positional astronomy calculations, is the Greenwich Mean Sidereal Time GMST http://zeitladen.de/time.html. Here, at 18Z,
GMST is 21h 36m 49.1s

These are related like this LST or LMST = GMST + East Longitude
http://home.att.net/~srschmitt/siderealtime.html

Local sidereal time (LST) = the RA on the observer's meridian

Jan Lustrup: Biography

See the previous issue (Aug/Sep 2008) for a more detailed biographical sketch. Jan is experienced in electronics. He spent most of his time in the last 30 years as a radio telecommunication electronics service engineer in Stavanger, Norway.

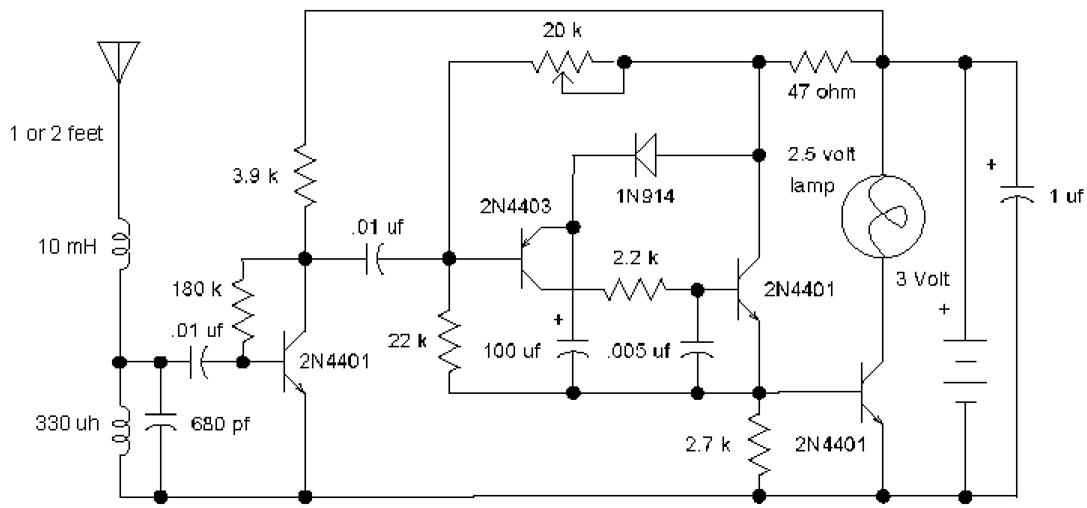
Figure 23: Jan Lustrup and his C-band antenna

~ Lightning Detector Circuits ~

Figure 1: Lightning at Sunset (source unknown, photograph likely enhanced)

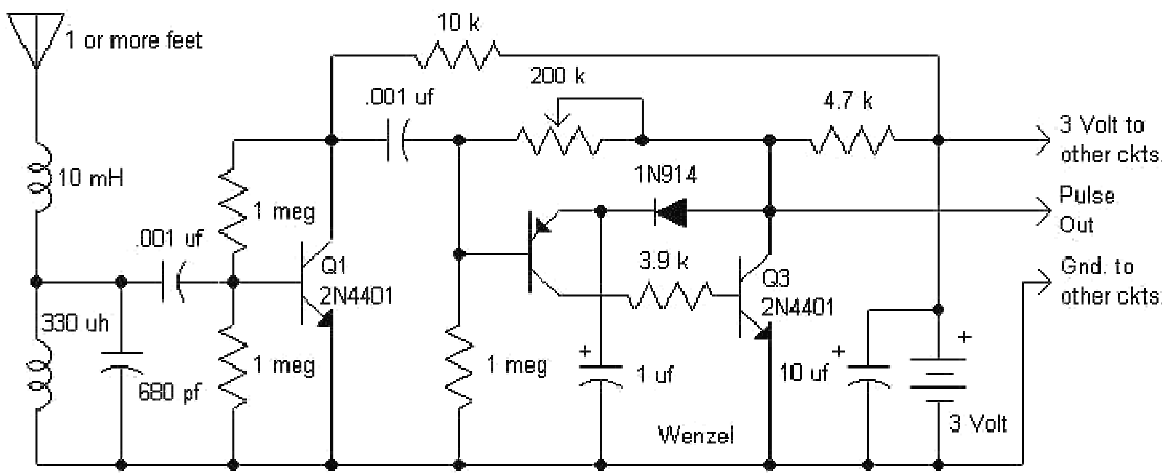
Editor's Note: In mid to late July 2008 on the on the Radio Jove listserve, the discussion of lightning detection spurred a flurry of responses. Tom Ziko, K4NAM, had kindly collated the original material from amateur radio operators and offered it to those interested. The original authors have yet to be determined. What follows is a major adaptation, restructuring, and enhancement of that information.

First, let's review the basic design (source unknown). Here is a LF receiver tuned to 300 kHz designed to detect the crackle of approaching lightning. A bright lamp flashes in synchrony with the lightning bolts indicating the proximity and intensity of the storm. Figure 1 shows the simple receiver which consists of a tuned amplifier driving a modified flasher circuit. The flasher is biased not to flash until a burst of RF energy, amplified by `the first 2N4401, is applied to the base of the 2N4403. The receiver standby current is about 350 microamperes, which is nothing at all to a couple of D cells, hardly denting the shelf life. Of course, the stormier it gets, the shorter the battery life.



Schematic 1: Basic Design of Lightning Detector

An improved design by Bob Radmore (N2PWP) appears in the April 2002 issue of *QST*, ARRL's monthly membership journal. It features lower battery drain and additional functions



Schematic 2: Improved Basic Low-Power Receiver

The preceding circuits maybe improved by modifying the antenna/RF section with 10 mH and 1 mH chokes, a 10 pF capacitor, and a 270 kΩ resistor. This modification removes a resonance in the lower part of the broadcast band that might make the detector susceptible to interference. The resulting circuits will work great. They may be adjusted for extreme sensitivity, if necessary.

The current receiver is similar to the first version except that the RF amplifier is a bit starved for current, which saves power and provides demodulation for listening to the lightning crackles. The flasher portion uses much less current but only provides a low current positive pulse, which needs further conditioning for most purposes. When idle, this new circuit draws only about 100 μA so applications using smaller batteries are practical. One or more of the following options are connected to the receiver to complete the detector:

The circuit used here is an improved version of the original Lightning Detector designed to run on a 5-volt supply (see note below). The new circuit features a superior RF section with a single resonance near 300 kHz and plenty of sensitivity. The potentiometer was eliminated; simply adjusting the length of the telescopic antenna will give the desired sensitivity. The circuit supply voltage was increased to 5 volts to allow the use of commonly available molded power supplies instead of batteries. Another not-so-obvious feature is that this design has plenty of the inductors!

[*Editor's Note: Though the originally referenced URL source, techlib/electronics, is now inoperative, the original circuit seems to be shown in an electronics lab projects site, http://www.electronics-lab.com/projects/science/001/index.html*]

Though lightning is a broadband emission source, 300 kHz is a good frequency to choose, as can be seen from the frequency spectrum of a lightning pulse.

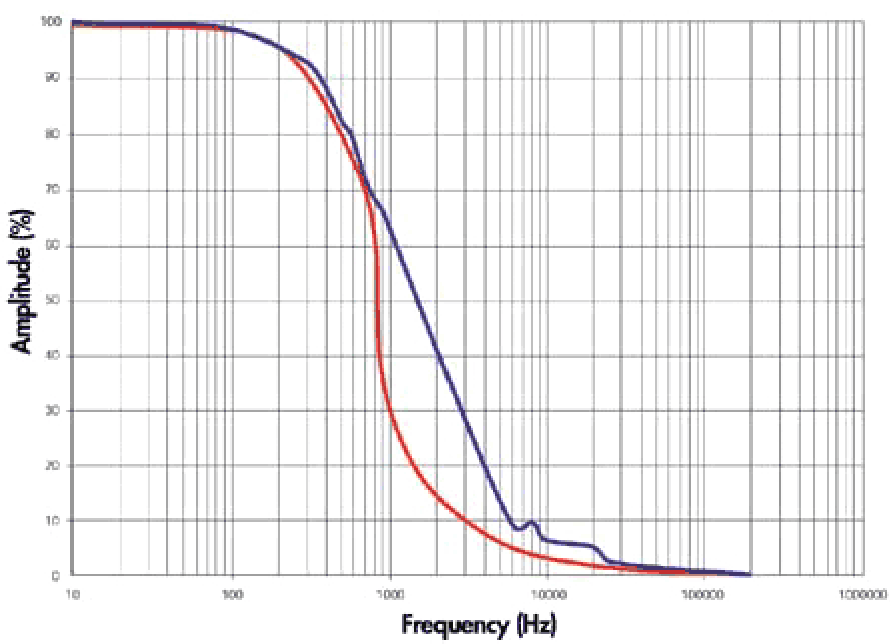
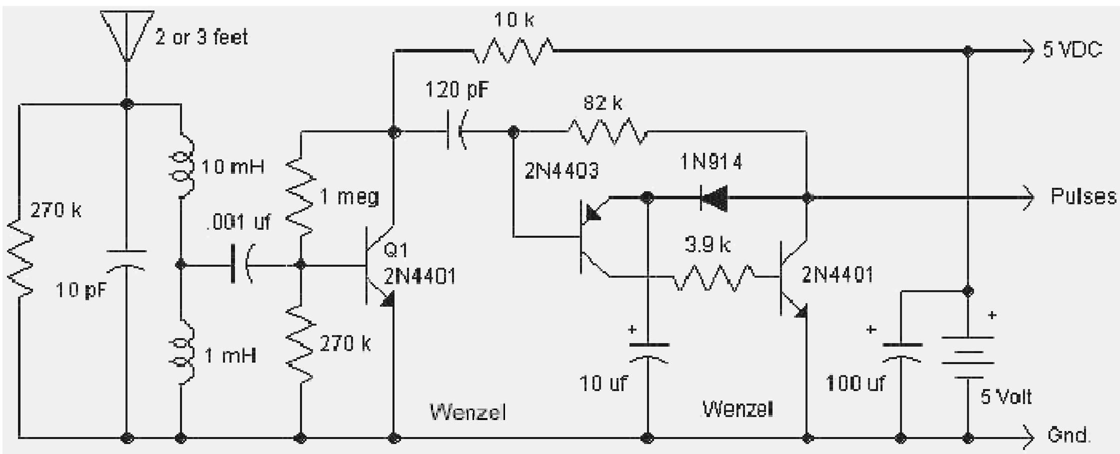


Figure 2: Lightning Frequency Spectrum (blue curve) (the red curve is a response curve for a Huber-Suhner protective device), http://www.hubersuhner.com/products/hs-p-rf/hs-rf-lightning-protectors/hs-p-rf-lp-kb/hs-p-rf-lp-kb-bas/hs-p-rf-lp-kb-bas-fre.htm

In the basic receiver schematic shown below, the antenna is a telescopic that can extend to two or three feet, but this length is not critical. A high-value resistor (270 kΩ) is connected from the antenna to ground to control the Q and this value may be lowered if the circuit seems unstable, but if the value is too low, it will destroy the sensitivity. The 10 mH and 1 mH chokes are molded types, but most moderately high-Q inductors will work fine and the rest of the parts are “run-of-the-mill” and not critical. The transistors are all general-purpose types.

Note: This circuit is intended to be used with one of the lamp options and any or all of the other options. If no lamp is desired, add a 1 kΩ resistor from the "pulses" output to 5 VDC.



Schematic 3: Current Design of Lightning Detector

<u>Theory of Operation</u>

Lightning flashes generate a broad spectrum of radio frequencies with especially intense emissions in the VLF band. This receiver is designed to pick up a band near 300 kHz, which is empty except for lightning static. These radio “crackles” are picked up by the antenna with the help of the 10 mH choke. Electrically short antennas (short compared to the wavelength) behave as though a very tiny capacitor. Connected with the choke, as shown, resonates, which allows current to flow into the receiver; i.e., the antenna, 10 pF capacitor, and the two inductors form a resonant tank at about 300 kHz. The two series inductors act as a matching network. The tuned circuit, via the 0.001 µF, couples into the base of the first transistor amplifier, Q1, now with a lower impedance than when signal was received by the antenna. The 270 kΩ resistor lowers the Q of the resonant tank to prevent oscillation. Q1 amplifies the 300 kHz bursts and applies the larger collector signal to the base of a PNP transistor (2N4401) that forms a monostable flasher circuit with the last NPN transistor (2N4403). When the RF signal pulls the PNP base voltage below the voltage on the 10 µF capacitor (plus about 0.6 volts), the PNP turns on, which then turns on the NPN. Since the NPN is connected to the base of the PNP through the 82 kΩ resistor, the PNP turns on even harder. This regenerative action causes the circuit to turn on quickly and fully, pulling the "pulses" line to nearly zero volts. The circuit stays on until the 10 µF capacitor discharges, at which point a similar reverse regenerative action causes the circuit to switch off quickly. The capacitor then quickly charges through the 1 kΩ resistor (in one of the lamp circuit options) and diode (1N914), and is ready for another pulse.

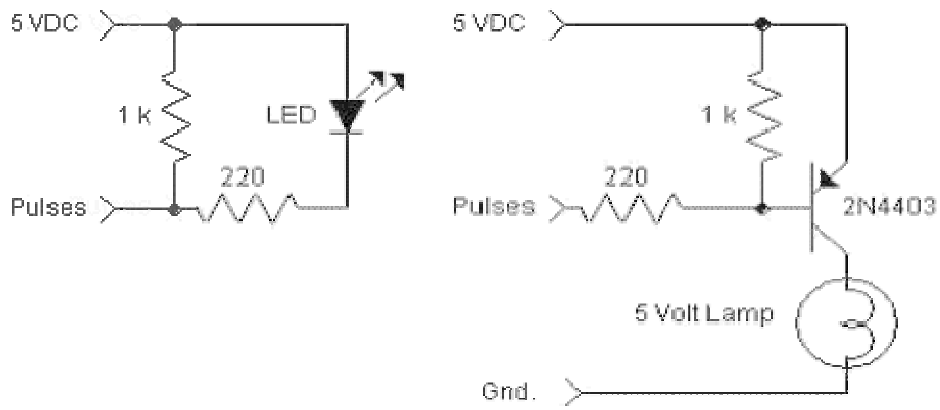
Note: Transistor substitutions are fine. Most modern small-signal transistors will work well in the circuit including 2N3904 (NPN) and 2N3906 (PNP). Avoid high frequency RF transistors since unwanted oscillations may result.

The prototype is built into a phenolic box using point-to-point wiring. The power switch is a single pole, double throw type having a "center-off" position. The power supply is connected to the center terminal and the speaker is connected to one of the outer terminals. Both of the outer terminals are also connected to the other circuitry through a couple of silicon diodes, one from each terminal. One diode keeps the speaker from getting power in the "speaker off" position and the other diode is simply there so that the circuitry sees the same voltage in both "on" positions. Alternately, a switch could be added in series with the speaker to turn it off. After one storm, you will add the switch if you don't include it at first! Alternately, a ordinary single pole, single throw switch could be used with another switch in series with the brown wire to disconnect the speaker when the constant crackle becomes too annoying.

Figure 3: Close-up of diodes and the power switch

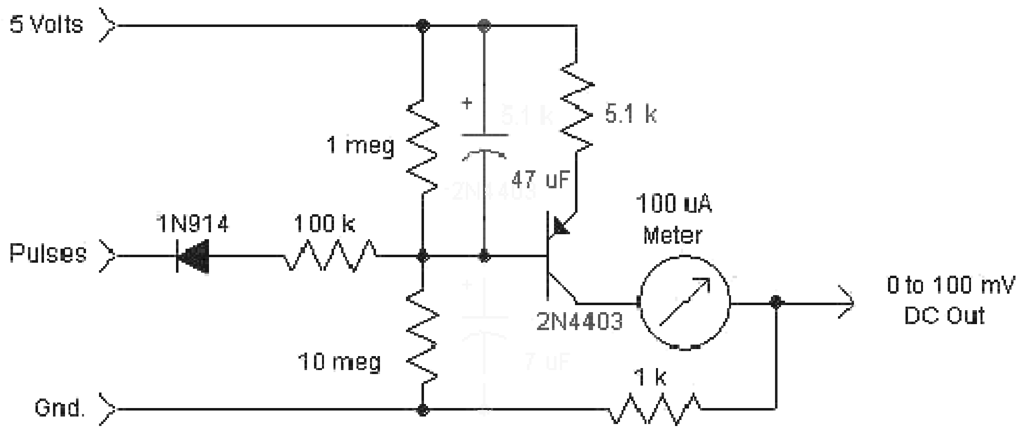
Associated Circuits

Schematics 5 & 6: LED or Lamp Circuits



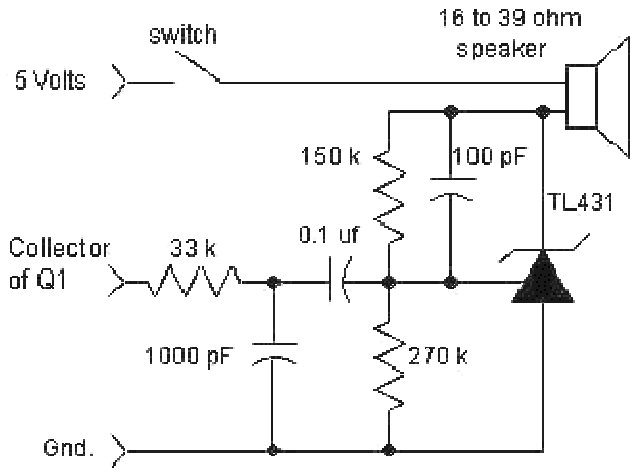
The next circuit will drive higher current lamps up to 500 mA. Flashlight bulbs make a bright flash.

Schematic 7: Averaging Meter Circuit



The averaging meter shows a steady reading that is proportional to the lightning activity. A DC output is provided for driving a comparator for alarms, automatic controls, etc. The meter sensitivity may be varied by changing the 5.1kΩ resistor.

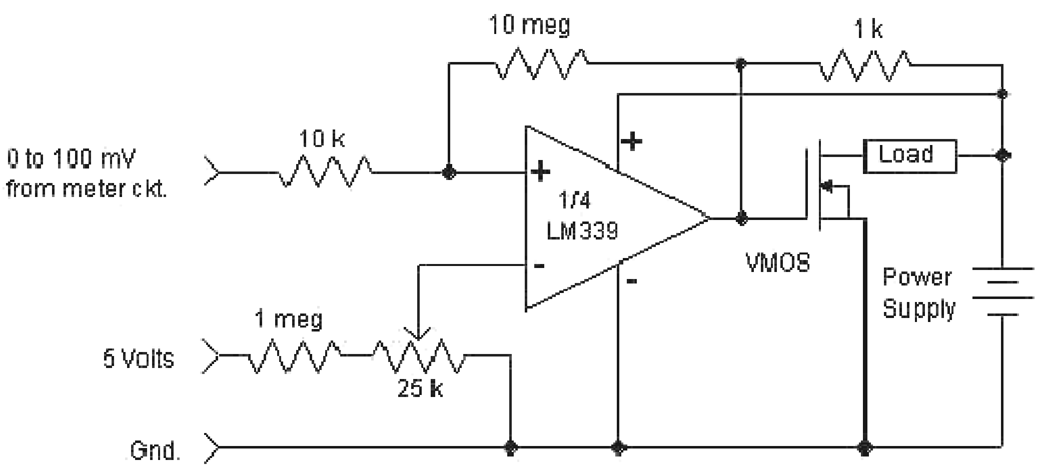
Schematic 8: Audio Circuit



The audio amplifier connects to the collector of Q1 and allows the user to listen to the received signal. No volume control is included, but the sound level is not particularly loud.

Choose any or all of the above circuits and connect them across the indicated terminals on the basic receiver. An alarm, buzzer, or other load may be activated when the lightning activity exceeds a preset level using the following circuit.

Schematic 9: Alarm Comparator Circuit



The alarm comparator is used to drive a buzzer or other type alarm, a motor, relay, or other heavy electrical load. A separate power supply provides power to the comparator and load, but the power supply may be the same 5-volt supply. A different voltage is fine as long as it is within the operating range of the op-amp or comparator. The 10 kΩ input resistor connects to the output of the averaging meter circuit and the 10 MΩ provides some hysteresis for quick switching. The 25 kΩ pot is adjusted for the desired trip point.

Any n-channel VMOS power transistor will work as long as it can adequately drive the load. A VN10KM is a typical component for lower current loads. Add a power switch in series with the load, if desired. In addition, an LM358 op-amp or other ground-sensing op-amp may be substituted for the comparator. Look for single-supply types for substitutes. The LM339 requires a pull-up resistor on the output, but op-amps will not require the 1 kΩ resistor.

Some Practical Considerations

For best effect, mount the lamp in an old-fashioned holder with an extra-large colored glass lens. Or construct your own fixture with a plate of textured colored glass behind a panel painted with black-crackle paint. Watch a few old science fiction movies for other ideas.

A different approach is to mount the circuit in an empty glass jar with the antenna and bulb protruding through the top. (A malted-milk jar has a nice, red plastic lid, which is easy to work, and looks good.) Use a pin jack for the antenna. The gadget looks quite home-made but fascinating.

Boat owners may wish to replace the lamp with a 5-volt beeper to provide an early warning of approaching bad weather. Choose one of those unbreakable clear plastic jars like the large jars of coffee creamer. A little silicone rubber will seal the antenna hole in the lid of the jar. Use a longer antenna for increased sensitivity since there are few electrical noise sources on the lake.

Tune-up is simple: adjust the potentiometer until the regular flashing just stops. (Use a multi-turn trimmer.) When properly adjusted, the lamp will occasionally flash when large motors or appliances switch on and off and an approaching storm will give quite a show. Obviously, tune-up is a bit more difficult during stormy weather. Adjust the pot with no antenna if lightning is nearby. Tune an AM radio to the bottom of the dial to monitor the pulses that the lightning detector is receiving.

This lightning detector is not so sensitive that it will flash with every crackle heard on the radio but will only flash when storms are nearby. Increased sensitivity may be achieved by increasing the antenna length. The experienced experimenter may wish to add another gain stage after the first by duplicating the RF amplifier circuitry including capacitor coupling with the addition of a 47 Ω emitter resistor to reduce the gain somewhat. This additional gain can cause stability problems if the layout is poor so novices are advised to use a longer antenna or adjust the sensitivity potentiometer more delicately instead! (When operating properly, the additional gain makes the pot adjustment much less critical.)

All of the options may be included in one unit. The photo below is the detector built into an abandoned control panel for an electronic air filter and the finished assembly. It includes the incandescent lamp, meter and speaker options.

Figures 4 and 5: Prototype lightning detector with 5-volt lamp driver, meter circuit, and speaker circuit

Supplemental Information

(1) The National Lightning Safety Institute
An Overview of Lightning Detection Equipment, Richard Kithil, President & CEO, NLSI
http://www.lightningsafety.com/nlsi_lhm/overview2002.html
Available technologies of the present day lightning detectors include:

a. Radio Frequency (RF) detectors measure energy discharges from lightning.
   They can determine the approximate distance and direction of the threat.
b. Interferometers measure lightning strike data more precisely.
c. The National Lightning Detection Network covers all the USA/Canada
   and reports lightning strikes to a central station.
d. Atmospheric Field Mill monitors measure the potential voltage gradient
   changes of the earth's electric to monitor lightning breakdown threshold.
e. Optical monitors detect cloud-to-cloud lightning that typically precedes
   cloud-to-ground lightning, which might provide earlier warning
f. Hybrid designs use a combination of the other single-technology designs.
g. Subscription Services

(2) *My Very Close Encounters With Florida Lightning Bolts*, KN41F,
http://www.kn4lf.com/kn4lf1.htm

(3) *Lightning: Physics and Effects*, Vladimir A. Rakov, Martin A. Uman, Cambridge University Press, 2007

The publishers say that this *is the first book [697 pages] to cover essentially all aspects of lightning, including lightning physics, lightning protection, and the interaction of lightning with a variety of objects and systems as well as with the environment.*

Accessible to the technical non-expert, it is addressed to anyone interested in lightning and its effects.

Excerpts are viewable in their e-book version, e.g., page 158 discusses some lightning pulse characteristics: http://books.google.com/books?id=TuMa5lAa3RAC&pg

(4) Products from several weather and lightning satellite databases

For example, aviation weather products may be more helpful than a generic weather report or forecast. Sky conditions and upper level winds could be helpful in assessing tropospheric effects on radio astronomy. The link to weather does require some familiarity with aviation terminology. Similarly, lighting data may shed some light on both tropospheric and stratospheric lightning that could affect analysis of radio astronomy signals. A current US Lightning Map is available as a free download (may require registration). Archived data is available for a fee.

(a) Aviation Weather Center supplies good meteorological data, especially with Aviation Digital Data Service, http://adds.aviationweather.noaa.gov/progs/
(b) Vaisala Lightning Explorer, http://thunderstorm.vaisala.com/explorer.html
the chart below only shows isolated lightning of the mid Atlantic coast

Figure 6: A quiescent map showing sparse lightning activity

Cited from the editor's website, *Adventures in Astronomy*, Radio Astronomy Web Tools, http://home.earthlink.net/~jcmannone/id3.html.

~ Solar Radio Astronomy Miscellany: Eurasian Resources ~

By John C. Mannone

In addition to the familiar radio Jove archives, the Australian Culgoora/Learmonth Spectrographs, the French Nancay Array, and a variety of satellites and space probes, there is a cadre of instruments to help solar research from more European and Russian sources.

http://helene.ethz.ch/rapp/cesra/cesra_home_nf.html, the CESRA, the Community of European Solar Radio Astronomers, has a useful link at the bottom of the page, *On-line data and lists of observations*, leading to http://helene.ethz.ch/rapp/cesra/sites_nf.html. You will see a dozen resources. I have reproduced them here and commented on some of them in red.

Whole-Sun dynamic spectra:

- IZMIRAN Solar Radio Observatory (Russia): dynamic spectra (25-50, 45-270, 220-260 MHz) and fixed-frequency (169 MHz, 204 MHz, 3000 MHz) observations

  Click on daily spectra archives, select year and date from calendar

- Ondrejov Observatory (part of the Astronomical Institute of the Academy of Science of the Czech Republic): dynamic spectra (2.0 - 4.5 GHz; 1.0 - 2.0 / 0.8 - 2.0 GHz to / from November 1997)

  Broken link

- Tremsdorf Solar Radio Observatory of the Potsdam Astrophysical Institute (Germany): lists of solar radio activity and selected dynamic spectra in the frequency range 40-800 MHz

  Radio data/monthly event list
  Data seems to stop in 2007

- Trieste Solar Radio Observatory (Italy): fixed-frequency observations (237, 327, 408, 610, 1420, 2695 MHz)

  http://radiosun.ts.astro.it/eng/load.php?la=0&pg=14&rf=300,
  Very nice site with solar radio archive

- ETH Zurich Radio Astronomy Group (Switzerland): dynamic spectra in the frequency ranges 100-1000 MHz and 0.1-8 GHz

  Look at the **Institute of Astronomy: Stellar and Solar Physics—ETHZ Radio Astronomy and Plasma Physics Group,** http://helene.ethz.ch/rag/.
  This was my original starting point as I explored the resources

  There is a variety of solar spectrometers and their data is available in FITS format.

  PHOENIX_3: FFT-spectrometer covering the frequency range in 4 bands from 1 GHz to 5 GHz in 2 polarizations (LHCP and RHCP), 131'072 channels every 200 milliseconds

  CALLISTO: Frequency agile spectrometer 45 to 870 MHz (in view of IHY2007) Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory

  ARGOS: Heterodyne FFT radio spectrometer

  PHOENIX-2: Computer-controlled instrument, covering 0.1 to 4 GHz (in operation since 1998)

  PHOENIX: Computer-controlled instrument, covering 0.1 to 3 GHz, 2000 measurements per second (in operation since 1988)

  IKARUS: Covered 0.11 to 1 GHz in steps of 1 MHz, 2000 measurements per second (predecessor of PHOENIX, in operation 1978 - 1985)

  DAEDALUS: Broadband analog solar radio spectrograph, covered 100-1000 MHz in one continuous linear sweep (successor of IKARUS, in operation 1972 - 1993

  Note: the RadioJove Archive, http://jovearchive.gsfc.nasa.gov/, with data at 20 MHz, might correlate with some of these spectrographs, such as Phoenix-2.

  From the menu bar, data access is via ASPECT (and a link back to CESRA).

Imaging observations:

- Metsähovi Radio Research Station (Finland): solar maps, single dish observations in the frequency domain 87-11.6 GHz

  14-meter telescope in the microwave
  Choose solar radio images/year 1994-2002

There is a useful background on solar research and correlation of microwave with x-ray emissions form the sun http://kurp-www.hut.fi/sun/general.shtml

- Nancay Radioheliograph (France): Solar maps at 164 and 327 MHz.

- Nobeyama Radioheliograph (Japan): Solar maps at 17 and 34 GHz

  http://solar.nro.nao.ac.jp/norh/
  Though data is limited, 17 GHz images of the sun are available

- RATAN-600 (Russia): one-dimensional scans of the Sun from 0.9 to 18 GHz (1.67 cm to 32 cm)

  http://w0.sao.ru/Doc-en/index.html
  http://w0.sao.ru/ratan/
  http://w0.sao.ru/hq/sun/ RATAN Solar Group

- Siberian Solar Radio Telescope (Russia): solar maps at 5.7 GHz

  http://ssrt.iszf.irk.ru/
  Click on observations (from 2000): 5.2 cm maps of the sun

General data (radio and others):

- The Institut National des Sciences de l'Univers / Observatoire de Paris provides a full disk archive of the Sun BAse Solaire Sol 2000 of optical and radio images produced in France.

  Includes Ca IIK data

- The Joint Organization for (optical) Solar Observations (JOSO).

  http://www.joso-info.org/JOSO_PROJEKT/main/index.htm
  Link is inoperative on the website. Google was necessary,
  but I could not open any of the links

There are many excellent solar astronomy resources. Here is a comprehensive list: from the AstroWeb Consortium maintained by NRAO: http://cdsweb.u-strasbg.fr/astroweb/solar.html

To supplement your study, consult the UCLA Space Science Center tutorials on space physics, http://www-ssc.igpp.ucla.edu/ssc/tutorial.html

~ Poetry of the Skies with Jocelyn Bell Burnell ~

By John C. Mannone

There are several visions I have, which I have shared with you repeatedly with varying degrees of emphasis over the last several years. One is my desire for SARA to have a more enhanced relation with the professional community. Though admirable in many ways, I personally aspire for more. The other is more personal, but I feel has profound effect on the way we "do" science and enjoy our hobby. It is the blending of the art with the science, the science with the art, which provides an unexpected synergism that emphasizes the "awe". And this in turn, promotes the inquisitive mind. Needless to say, I became ecstatic when I discovered one of the most revered scientists in radio astronomy has a penchant for poetry. Professor Jocelyn Bell Burnell, the discoverer of pulsars, has given lectures on poetry on BBC radio, and more recently, co-edited a book of poetry.

Though I have learned of her radio broadcast on the *Poetry of the Skies* several months ago, I only recently communicated with her about it. An astronomer with a long-standing interest in literature, Professor Bell Burnell focused on poetry from the last 50 years. She considered whether poets engage with the science and if poetry has followed the major developments in astronomy. The talk, *Astronomy and Poetry*, included poetry readings.

Professor Bell Burnell said, *I couldn't be without science, but that alone doesn't satisfy me. I have "collected" poetry with an astronomical theme for many years. There's an amazing amount out there, I have approximately 150 poems just from the last 50 years.*

Let me share with you the gist recent communications I have had with Dr. Burnell, through which you will learn of her artistic side.

I wrote to the Professor,

Ever since I became an avid member of the Society of Amateur Radio Astronomers (SARA), I have always been fascinated with your contributions, most notably your seminal work on pulsars and the interesting history behind your discovery. And because I love to teach, I share these things with my college students whenever pulsars come up, and that is quite often. But today, I am writing you about another passion of mine-poetry.

Recently, I had discovered your lecture on the Poetry of the Skies given at the University of Bath almost exactly two years ago (http://www.bath.ac.uk/news/articles/archive/gulp-bellburnell101006.html). I thoroughly enjoyed the mp3 recording, which is what prompted this note to you.
(http://www.bath.ac.uk/lmf/download/015-podbath-JocelynBellBurnel/17447.mp3)
It is always a delight to find scientists who appreciate, let alone write, literary quality poetry. It is considerably more rare for the subject of their poetry to embrace astronomy beyond a tired cliché or voice a silly or didactic rhyme (or a limerick) than to skillfully craft their poem. Though still a student of the art, I indeed strive to accomplish that crafting.

Because I am also the Senior Editor of the SARA Journal, Radio Astronomy, I have made part of my charge to blend science and art in the publication. On our website, http://radio-astronomy.org/, and somewhat towards the bottom right, you will find a sample journal shortly after I took the appointment as editor in November 2006. It was a special issue featuring pulsars and you might enjoy the way I packaged the information, departing from what most would have expected.

To that end, I would dearly like to solicit from you a contribution to our Journal— an article or an interview-on any topic you wish to discuss, but I hope you would address this wonderful blending of science and art, of astronomy and poetry, however long or short.

I realize that you are extremely busy, but if you could manage some time for us, we would be deeply indebted. I promise a captive audience. I sincerely hope you will honor us with a contribution to our humble publication.

Cordially,
John C. Mannone
SARA Senior Editor

I was delighted to hear back, but unfortunately her busy schedule precludes an article. She is now the head of the Institute of Physics. The *Telegraph* reports, "Jocelyn Bell Burnell, a woman on a mission to reveal the friendly face of physics," http://www.telegraph.co.uk/scienceandtechnology/science/sciencenews/3425013/Jocelyn-Bell-Burnell-a-woman-on-a-mission-to-reveal-the-friendly-face-of-physics.html.

However, I did learn of Dr. Burnell's new book,

You might also be interested in a recent book I have edited - Dark Matter: Poems of Space. It is published by the Calouste Gulbenkian Foundation here in London UK. Maurice Riordan and I are the co-editors; it is an anthology of poetry about space and astronomy, and includes about 20 new commissions. It came out a few weeks ago.

Regards,
Jocelyn Bell Burnell

Of course, I set out to learn more about the book:

Dark Matter: Poems of Space, Ed. Maurice Riordan, Jocelyn Bell Burnell, Calouste Gulbenkian Foundation (published 27 Oct 2008), (Paperback) 240 pages. English.
ISBN-10: 190308010X, ISBN-13: 978-1903080108, RRP: £8.50

I found it available in the US, new, with a 5- to 8-day delivery by Royal airmail from The Book Depository. The cited cost is $9.66 (plus $3.99 shipping for *each* copy). See http://www.amazon.com/gp/offer-listing/190308010X/ref=dp_olp_0?ie=UTF8&qid=1225911417&sr=11-1&condition=all

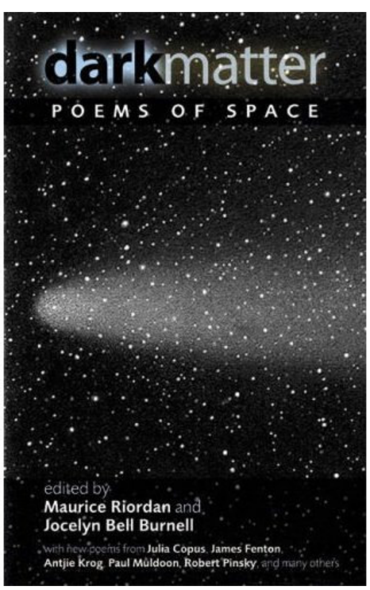
Book Description

Poets have long been stargazers, moved by the strange infinities of the universe to translate them into metaphor and song. For 'Dark Matter', the third in the Gulbenkian Foundation s trilogy of poetry and science anthologies, leading poets were commissioned to create new work inspired by their discussions with eminent space scientists. Their meditations on the light and dark matters of the skies have been challenged and shaped by their encounter with the critical investigations of astrophysics, whether it s John Kinsella reflecting on the light echo of supernova 1987A, Antjie Krog recreating the symmetry of the HH212 gas jet or Paul Muldoon's jaunty take on the expanding universe. The commissioned works are complemented by the editors' selection of well-known and lesser-known poems from across the ages: John Donne and Emily Dickinson share the stratosphere with Philip Larkin and Adrienne Rich in their explorations of the spaces beyond our world, their ability to make sense of these and to create art from the unknown.

Information about the Authors-Editors

Maurice Riordan received the 2007 Michael Hartnett Award for his latest collection, 'The Holy Land' (Faber), while previous collections, 'A Word from the Loki' and 'Floods', were nominated for a TS Eliot Prize and a Whitbread Book Award. His other publications include 'A Quark for Mister Mark: 101 Poems About Science', the ecological anthology 'Wild Reckoning', and 'Hart Crane', which has recently appeared in Faber`s Poet to Poet series. Born in Lisgoold, Co Cork, he lives in London and edits Poetry London. Jocelyn Bell Burnell DBE is Visiting Professor of Astrophysics at the University of Oxford. As a post-graduate student at Cambridge, she was involved in the discovery of pulsars, for which her supervisor won a Nobel Prize. She has received numerous awards for her work, in the UK and USA, and is President of the Institute of Physics. She has long collected poems on astronomy and contributed to the OUP anthology, 'Contemporary Poetry and Contemporary Science', in 2006.

Publisher's Website:



The Calouste Gulbenkian Foundation is well known for its pioneering work in the field of art and science and its seminal publications in this area. Strange and Charmed: Science and the contemporary visual arts *(2000) has inspired numerous adventurous research collaborations and residencies in both science and arts organizations.* Science, not Art: Ten scientists' diaries *(2003) was BBC Radio 4 'Book of the Week' in February 2004. The Foundation continues to explore the possibilities of cross-cultural dialogue between the arts and science and to facilitate a wider interest in and understanding of both.*

http://www.gulbenkian.org.uk/

Below is an excerpt from the book Enjoy the prose poem by one of the new generation poets, Jamie McKendrick. I found it in a press release published The Financial Times Ltd., November 1 2008 02:00, http://www.ft.com:

Out There

If space begins at an indefinite zone, where the chance of two gas molecules colliding is rarer than a green dog or a blue moon then that's as near as we can get to nothing. Nostalgia for the earth and its atmosphere weakens the flesh and bones of cosmonauts. One woke to find his crewmate in a space suit and asked where he was going. For a walk. He had to sleep between him and the air-lock. Another heard a dog bark and a child cry halfway to the moon. What once had been where heaven was, is barren beyond imagining, and never so keenly as from out there can the lost feel earth's the only paradise.

Jamie McKendrick was born in Liverpool in 1955, studied at Nottingham University and taught for some time at the University of Salerno in Italy. He is the author of five collections of poetry. More details are found here, http://www.contemporarywriters.com/authors/?p=auth519D18CE02e1d1664FOpYyDA1F18. More of his poetry (but not from the book) are found here (see *Oil and Blood*), http://www.thepoem.co.uk/poems/mckendrick.htm.

Subsequently, I had replied to Dr. Burnell about her book and about some of my own poetry:

Hello Professor Jocelyn Bell Burnell,

It is so good to hear from you. Thank you for taking time from your busy schedule to reply to me…

Your book, Dark Matter: Poems of Space, sounds intriguing to me. I've scoured the internet to learn more about it and found some information from the publisher, Calouste Gulbenkian Foundation, and an excerpt (Out There) by Jamie McKendrick in the Financial Times Ltd 2008. I found one US source of your book (The Book Depository via Amazon), but is there anyway I could purchase an autographed copy? I plan to feature this book in the next issue of Radio Astronomy, SARA's Journal. This will be the next best thing to an article on art and science from you!

I hope you had a chance to read some of my poetry, which I had attached previously. Your opinion would be priceless to me.

Good luck with your new position and I hope to hear from you soon, *Best regards,*

John C. Mannone
SARA Senior Editor

If I learn any new things about the book, I will gladly report it "From the Editor's Desk" in the future issue.

You might be interested in my own astronomy-related poetry (I had directed Dr. Jocelyn Bell Burnell attention to it too). See the online poetry magazine, *Astropoetica: Mapping the Stars Through Poetry*, in which I had published a couple of my earlier poems: *Pearls in Galactic Oysters* (Summer 2007) and *The Final Fling* (Spring 2006). Here are the links:

http://www.astropoetica.com/Summer07/pearls.html,
http://www.astropoetica.com/Spring06/finalfling.html

I also shared, *Tabernacles Among the Stars* and *Extinction Level Event*, which are currently short-listed for publication in *Liquid Imagination*.

I hope you make the time to listen to the 25 MB audio broadcast (more than 50 minutes long) hosted by Professor Jocelyn Bell Burnell, as well as look into her new book hot off the press.

~ Organizational Structure ~

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