Summary of Solar Radio Emission Types and Characteristics

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Solar cycle 25 began in December 2019 and already has produced many radio bursts and magnetic disturbances in the 20 months since then. The cycle is in full swing, and it is time to review the types and characteristics of radio emissions that might be detected throughout a solar cycle. Geomagnetic effects will be reviewed in a future article.

Figure 1 illustrates the frequency-time characteristics of solar radio phenomena. Table 1 provides a general description of the spectral classifications that correspond to figure 1, and table 2 provides more detailed descriptions of the major characteristics for each burst type. For actual spectrographic images of the various solar radio phenomena, see {Catalog} and {Reeve13}. On a very broad basis, solar radio emissions consist of radio bursts or radio continuum, or a combination of the two. Bursts sweep through a range of frequencies while continuums are broadband noise phenomena that sometimes have a bursty nature but do not sweep.

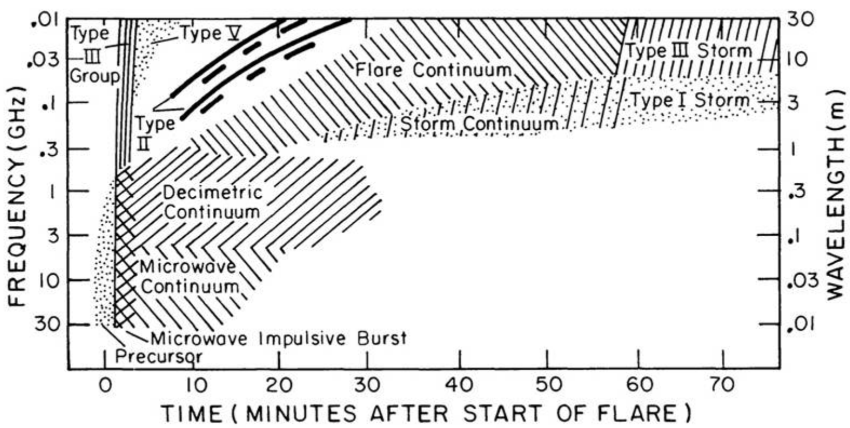


Figure 1 ~ Solar Radio Bursts ~ Frequency-Time Characteristics. Source: Figure 11, [Dulk]

Solar radio emissions associated with flares have the highest received power level of all celestial radio sources. Some of the emissions can be received with just about any shortwave receiver and a simple antenna such as a dipole. Solar radio emissions generally are easy to recognize in the narrowband audio output from ordinary high frequency receivers or in the wideband spectral signatures displayed by software defined radio (SDR) receivers and radio spectrometers.

When a burst is received, the background noise heard in the receiver output increases in volume, peaks and then decreases. The audio output may be connected to a PC soundcard and plotted, for example with Radio-SkyPipe software (figure 2). The plots often (but not always) show a characteristic *shark fin* shape with a more rapid rise than decay. If the received emissions are processed by an SDR receiver or spectrometer, the signal intensities displayed on a spectrogram brighten during the burst (figure 3). Generally, solar radio emissions received on Earth are strongest and most common in the high frequency band; however, Earth's ionosphere blocks solar radio emissions below 10 to 15 MHz.

Although solar radio emissions cannot be received directly at frequencies below about 15 MHz, solar flares can be detected indirectly by LF and VLF receivers and a modest loop antenna. In this case, it is the flare x-ray and extreme ultraviolet radiation that causes the effect, not the radio radiation. The flare radiation enhances the ionization in Earth's lower ionosphere (D-region), which affects the propagation of the low frequency transmissions from high-power transmitters used for submarine communications or time-frequency dissemination. When the output from a VLF or LF receiver is plotted, the flare usually is seen as an enhancement in the signal level, and this is called a sudden ionospheric disturbance, or SID (figure 4).

Table 1 ~ Solar Radio Burst Spectral Classifications: General (see also table notes below)

Type	Characteristics	Duration	Frequency Range (MHz)	Associated Phenomena
I	Short, narrow-bandwidth bursts. Usually occur in large numbers with underlying continuum	Single: ~1 second Storm: hours – days	80 – 200	Active regions, flares, eruptive prominences
II	Slow frequency drift bursts. Usually accompanied by a second harmonic	3 – 30 minutes	Fundamental: 20 – 150	Flares, proton emission, magneto-hydrodynamic shockwaves
III	Fast frequency drift bursts. Can occur singularly, in groups, or storms often with underlying continuum. Can be accompanied by a second harmonic	Single: 1 – 3 seconds Group: 1 – 5 minutes Storm: minutes – hours	0.01 – 1000	Active regions, flares
IV	Stationary Type IV: Broadband continuum with fine structure	Hours – days	20 – 2000	Flares, proton emission
	Moving Type IV: Broadband, slow frequency drift, smooth continuum	0.5 – 2 hours	20 – 400	Eruptive prominences, magneto-hydrodynamic shockwaves
	Flare Continua: Broadband, smooth continuum	3 – 45 minutes	10 – 200	Flares, proton emission
V	Smooth, short-lived continuum. Follows some type III bursts. Never occurs in isolation	1 – 3 minutes	10 – 200	Same as type III bursts
VI	Series of Type III bursts over a period of 10 minutes or more, with no period longer than 30 minutes without activity	> 10 minutes	See Type III	See Type III
VII	Series of Type III and Type V bursts over a period of 10 minutes or more, with no period longer than 30 minutes without activity	> 10 minutes	See Type III and Type V	See Type III and Type V

Table notes:
1. Drifting bursts almost always drift from high to low frequencies
2. Frequency range is the typical range in which the bursts appear and not their bandwidth
3. Sub-types of Type IV are not universally agreed upon

For continuously updated information on the progress of the current solar cycle, see {NOAA}. The Space Weather Prediction Center (SWPC, part of NOAA) provides daily reports of solar activity, or *Events*, which include radio bursts. The Events reports are ASCII text files that may be downloaded at {SWPCEvnt}. These reports use many abbreviations, which are defined at {README} (also a text file) and essential to understanding the reports. SWPC provides many other space weather *products*, all free, that may be downloaded or viewed; a good place to start is their homepage at {HOME}. From there, various dashboard may be accessed as well as reports, forecasts, and archived data.

Additional important sources of information are fellow radio astronomers, especially those who observe at the same time and frequency. Time correlation of radio emissions received at two or more geographically separated locations is an excellent verification method because it eliminates local radio frequency interference (RFI) as a possible source for the event. Some solar radio emisisons are indistinguishable from RFI.

Table 2 ~ Solar Radio Bursts: Summary of Major Characteristics
(Source: Table 1, [Dulk])

Burst type	**Duration at 100 MHz or 10 GHz**	**Temperature (K)**	**Polarization (circular)**	**Frequency range/ bandwidth**	**Height range/ magnetic topology**	**Association**	**Emission mechanism**
I	≤ 1 s	≥ 10^{10}	50 – 100%	50-300 MHz/ ~1 MHz (burst)	0.1 – 0.6 R_0/ closed	large sunspots	fundamental plasma
I storm	days to weeks	≥ 10^{10}	o-mode	~100 MHz (storm)			
III storm	days to weeks	≥ 10^{10}	o-mode	50 MHz – 30 kHz/	0.6 R_0 – 1 AU/ open	Type I storms	fundamental and/or harmonic plasma
II	≥ 10 min	10^8 – 10^{11}	usually unpolarized	200 → 1 MHz/ 10 MHz	0.2 – 200 R_0/ open	flare shockwave	fundamental and harmonic plasma
III	few seconds	10^8 – 10^{12} (to 10^{13} at ~ 1 MHz)	fundamental: 30% harmonic: 10% o-mode	200 → 1 MHz/ 10 MHz 2 harmonics	0.2 – 200 R_0/ open (closed for U or J burst)	c/3 electron stream	fundamental and harmonic plasma
IV moving	~ 30 min	10^8 – 10^9	low → high x-mode	200 → 10 MHz/ > 10 MHz	0.5 - few R_0 / plasmoid	small flare	gyrosynchronous and/or plasma
IV flare continuum	~ 20 min	10^8 – 10^{12}	0 – 40% o-mode ?	200 → 10 MHz/ 100 MHz	0.1 – 1 R_0/ closed ?	moderate to large flare, initial phase	plasma ?
IV storm continuum	few hours	> 10^8	60 – 100% o-mode	50 – 300 MHz/ 100 MHz	0.1 – 0.6 R_0/ closed ?	flare, late phase	fundamental plasma
V	> 1 min	10^8 – 10^{11}	< 10% x-mode	100 → 10 MHz/ 50 MHz	0.5 – 2 R_0/ open ?	follows some Type IIIs	harmonic plasma
Microwave impulse	> 1 min (at 10 GHz)	10^7 – 10^9	~ 30% x-mode	3 – 30 GHz/ 10 GHz	~ 10^4 km closed	small to large flares hard x-rays	gyrosynchronous (Maxwellian or power law)
Microwave IV	~ 10 min	10^7 – 10^9	~ 10% x-mode	1 – 30 GHz/ 5 GHz	10^4 – 10^5 km closed	large flares with shocks	gyrosynchronous (power law)
Microwave postburst	minutes to hours	~ 10^7	low	1 – 10 GHz/ 5 GHz	10^4 – 10^5 km closed	flare, late phase	thermal bremsstrahlung
Microwave spike burst	~ 10 ms (burst) ~ 10 min (group)	> 10^{13}	~ 100% x-mode ?	~ 0.5 – 5 GHz/ few MHz	10^4 – 10^5 km closed	flare, hard x-rays	cyclotron maser

Solar radio emissions will increase over the next several years as the solar cycle progresses. Radio activity will continue even after the solar cycle peaks, but there is no better time to start monitoring than now.

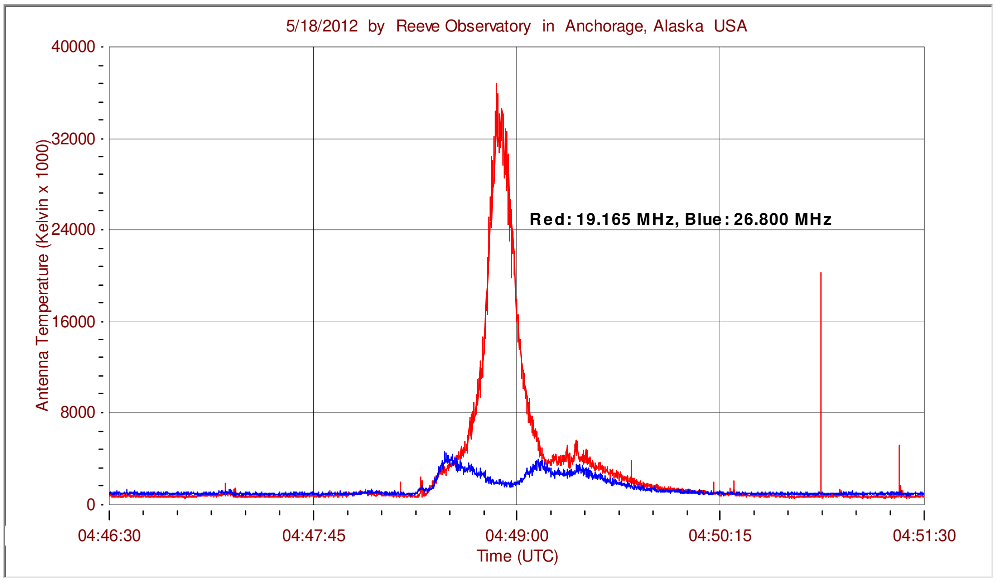


Figure 2 ~ Narrow slices of spectrum at two frequencies plotted over a 5-minute period with Radio-SkyPipe software at Anchorage, Alaska on 18 May 2012 during solar cycle 24. The peak received power (antenna temperature) of this solar radio burst at 19.2 MHz was about 35 million K. The descending frequency sweep of this burst is apparent – note that the blue trace (26.8 MHz) peaks before the red trace (19.165 MHz).

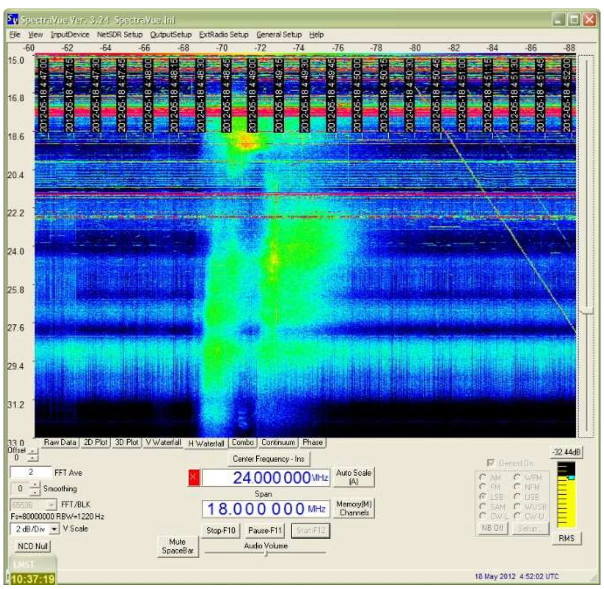
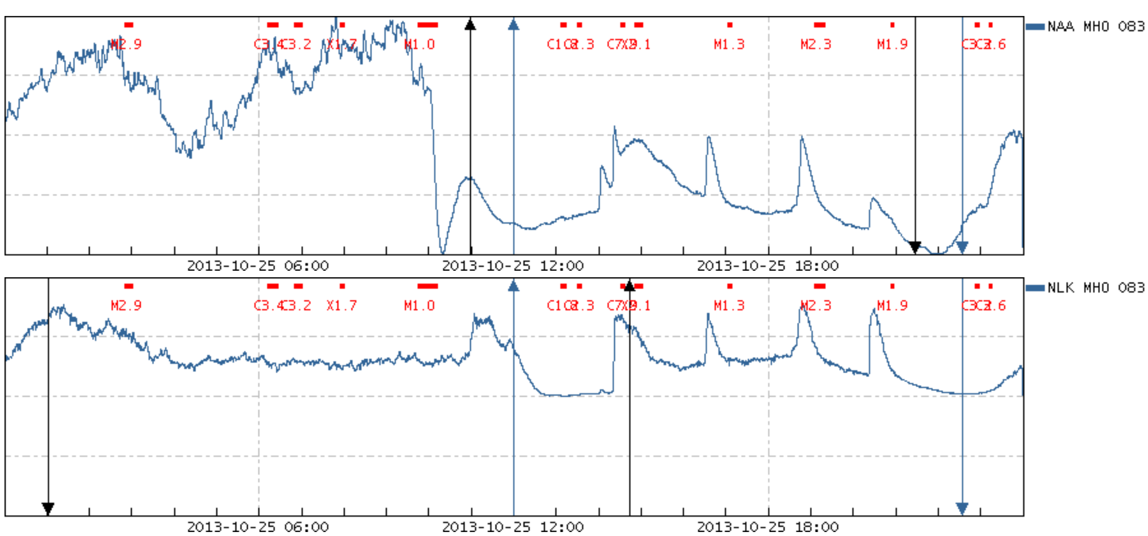


Figure 3 ~ Horizontal waterfall spectrogram of the 18 May 2012 solar radio burst over a 5-minute period received with an SDR receiver and associated software at Anchorage, Alaska. This spectrogram shows a wideband representation of the burst plotted above over the frequency range 15 to 33 MHz. Frequency is labeled on the left vertical scale (increasing top-to-bottom). Time from 0447 to 0452 is on the horizontal scale at top (left-to-right). The plot of the intensity of a horizontal line of pixels at 19.165 MHz would show a trace similar to the red trace in the above plot. The slanted yellow lines on the right side are *sweepers* from ionosondes or over-the-horizon radars. The diffuse horizontal turquoise swaths are radio interference. The other horizontal features include radio interference and radio stations.



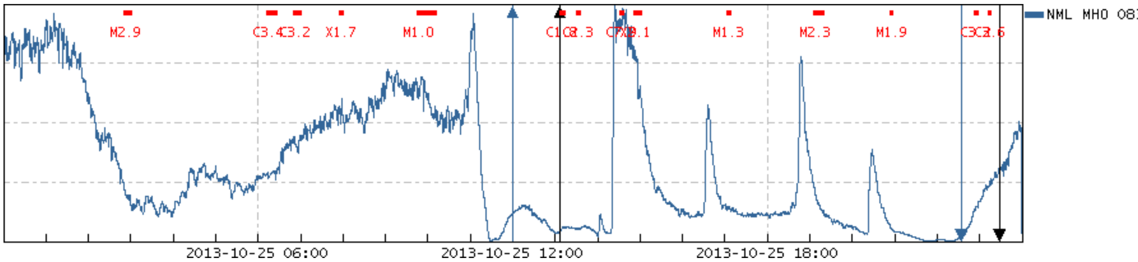


Figure 4 ~ Three plots for 25 October 2013 during solar cycle 24 of low frequency received signal level (vertical scale) with respect to time (UTC, horizontal scale). The transmitter sites are, top-to-bottom, NAA (24.0 kHz) in Maine, NLK (24.8 kHz) in Washington and NPM (21.4 kHz) in Hawaii; all are in USA. The receiver site is in Michigan USA and maintained by Tom Hagen. The black up-arrow indicates sunrise and the black down-arrow indicates sunset at the transmitter site in each plot. Similarly, the blue up- and down-arrows indicate sunrise and sunset at the receiver site. Relatively high, short-term signal variations occur during the night at the receiver site, especially between about 0000 and 1100 UTC. Except for station NLK, the received signal levels rise at night. Numerous solar flares are marked along the top of each plot, including several M-class (moderate) and one X-class (extreme) flares; some flares overlap. The corresponding SIDs with their signature shark-fin shape can be seen in the traces immediately below the flare labels. Images source: Stanford Solar Center {SSCData}.

Weblinks & References:

[Dulk] Dulk, G., Radio emission from the Sun and Stars, 1985, available at: http://adsabs.harvard.edu/abs/1985ARA&A..23..169D

{Catalog} http://www.e-callisto.org/GeneralDocuments/BurstCatalog.pdf

{NOAA} https://www.swpc.noaa.gov/products/solar-cycle-progression

{README} ftp://ftp.swpc.noaa.gov/pub/indices/events/README

{Reeve13} http://www.reeve.com/Documents/CALLISTO/Reeve_SolarRadioBurstCatalog_SARA2013West.pdf

{SSCData} http://sid.stanford.edu/database-browser/

{SWPCEvnt} ftp://ftp.swpc.noaa.gov/pub/indices/events/

Document Information

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