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# **SRT Documentation Documentation**

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# CHAPTER 1

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## Introduction

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The Sardinia Radio Telescope is a 64-meter single-dish radio telescope. It is located in the Pranu Sanguni area of San Basilio, Sardinia, Italy, about 40 km north of Cagliari.

Its state-of-the-art technology includes an active surface with 1008 panels, which allows observations at high frequencies (from 0.3 up to 115 GHz). There are three main focal points where receivers can be placed: primary focus (currently hosting the L-P dual band receiver); Gregorian focus (K-band receiver), and Beam Wave Guide focus (C-band receiver). In total, the telescope can accommodate up to 20 receivers. A number of additional receivers are currently being planned and built.

The telescope can be operated in single-dish or VLBI mode for radio astronomy, geodynamical studies or space science. Its geographical location allows it to observe at declinations above -33 degrees.

A general description of the SRT, including technical commissioning information and first light results, can be found in the technical commissioning paper: [Bolli et. al, Journal of Astronomical Instrumentation, Vol. 4, Nos. 3 & 4 \(2015\) 1550008](#).

Scientific tests and applications for the SRT are described in the following scientific validation paper: [Prandoni et. al, A&A 608, A40 \(2017\)](#).

Science done with SRT during its early-science run (2016) with the various hardware and software described below can be found here: [Science with SRT](#).

In the following sections, we outline information that is useful for observing with the SRT in the current call for proposals (published September 14, 2018 with a deadline of October 9, 2018). We note that remote observing is not currently available for the Sardinia Radio Telescope; each proposing team will need to send at least one observer to the SRT to prepare the observing schedules and perform the observations on site.



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## Antenna

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The Sardinia Radio Telescope (SRT) is a 64-meter Gregorian radio telescope with shaped optics, a quasi-parabolic main mirror and a quasi-elliptical subreflector.

The antenna's main characteristics are:

Position	Pranu Sanguni, San Basilio, Sardinia
Geodetic Coordinates	Lat 39° 29' 34.93742" N; Long 9° 14' 42.5764" E (WGS84)
Optical configuration	Primary, Gregorian & Beam Waveguide (BWG)
Primary mirror diameter	64 m
Subreflector diameter	8 m
Focal positions	primary $f/D = 0.33$ ; Gregorian $f/D = 2.34$ ; Beam waveguide (BWG) $f/D = 1.8$
Azimuth range	-90 to 450 degrees
Elevation range	5 – 90 degrees
Slew rate	0.85 degrees/s in azimuth; 0.5 degrees/s in elevation
Frequency coverage	0.3 – 115 GHz
Primary surface accuracy	300 $\mu\text{m}$ rms
Pointing accuracy (rms)	2 – 5"

We note that while the elevation limits range from 5 to 90 degrees, observations should be planned for an elevation between 6 and 82 degrees. Only in exceptional cases should the observations go below 6 degrees or above 82 degrees.

### Active surface

The primary reflector, which is 64 m across, is made of 1008 aluminium panels (with an RMS 65  $\mu\text{m}$  each) driven by 1116 electromechanical actuators. This *active surface* is designed to compensate for the gravitational deformations of the whole surface at different elevations.

The observer can choose among three configurations:

- shaped in tracking (it adjusts according to the observed elevation position)
- parabolic in fixed position (optimized for El=45°)
- parabolic in tracking (it adjusts according to the observed elevation position)

The shaped configuration is used for receivers in the Gregorian and BWG foci, while the parabolic configurations are used for the primary focus systems.



# CHAPTER 3

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## Receivers

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In the current call for proposals, the following (cryogenically-cooled) receivers are available in both single-dish and VLBI modes:

RF band (GHz)	Type	Tsys@90degE (K)	Beam size (arcmin)	Max gain (K/Jy)	connected backends
P 0.30-0.36	single-feed	50-80	48	0.52	DBBC,ROACH1
L 1.3-1.8	single-feed	25-35	11.4	0.55	DFB,DBBC,ROACH1,SARDARA
C-high 5.7-7.7	single-feed	32-37	2.7	0.66	TP,DFB,DBBC,ROACH1,SARDARA,XARCOS
K 18-26.5	7-feed	90	0.8	0.66	TP (MB),DFB,DBBC,ROACH1,SARDARA (MB),XARCOS(MB)

(MB) means that the Multi-Beam option is available for observations in K-band with the TP, XARCOS and SARDARA backends.

- The single-feed, L-P band dual-frequency receiver was installed at the primary focus of the telescope, and therefore requires the parabolic configuration. It allows for simultaneous observations at L and P bands. The polarization type is linear but is also transformed to circular thanks to a hybrid converter.
- A single-feed C-high band receiver is installed at the Beam Wave Guide (BWG) focus of the telescope. The polarization type is circular.
- A multi-feed K-band receiver is installed at the (secondary) Gregorian focus. Both C and K band receivers require the shaped configuration. The polarization type is circular.

In the following table, we outline, for each receiver: its frequency coverage; number of feeds; polarization type; focal position; its beam-size in arcmin or arcsec; measurements of the system temperature Tsys at 45 degrees of elevation and antenna gain. Each receiver feed allows for two polarizations.

Band	Frequency coverage (GHz)	Feeds	native polarization type	Focal position	Beam size	Tsys (K)	Gain (K/Jy)
P	0.30 – 0.36	1	linear	primary	48'(*)	[50-80]	0.52
L	1.3 – 1.8	1	linear	primary	11.4'(*)	25-35	0.55
C-high	5.7 – 7.7	1	circular	beam waveguide	2.7'	32-37(*)	0.66 (*)
K	18 – 26	7	circular	Gregorian	0.8'(**)	90(**)	[0.66]

[ ] is an estimate (\*) at the band's central frequency (for C-band: 45 degrees EL @ 7.3 GHz) (\*\*) at 22.3 GHz with opacity 0.1 and ground air temperature of 293K.

The FWHM beam size, as a function of the frequency  $f$ , can be approximated by the following rule:  $FWHM(\text{arcmin}) = 19.7 / f(\text{GHz})$

SRT receiver changes are quick, allowing for an efficient frequency agility. The selected receiver is set in its focal position within at most a few minutes. However, the use of a Gregorian cover to limit RFI in L/P band observations does not currently allow a quick receiver change between L/P bands and other bands (C or K). Receiver changes between C and K-bands are not affected. An automatic system for the installation and removal of the Gregorian cover is currently under development and will permit smooth and efficient frequency changes.

*Special considerations about the L/P dual-band receiver:* the RFI levels need to be minimized. A Gregorian cover limits RFI at L and P bands; if desired, it needs to be requested in the observation proposal. However the availability of the Gregorian cover is not a priori guaranteed.

*Special considerations about the multi-beam K-band receiver:* we have measured the sensibility of each channel. Here are the details below:

Feed,Pol	RMS(mJy)	Ratio w/feed2,pol1
Feed0,Pol0	19	1.00
Feed0,Pol1	27	1.42
Feed1,Pol0	18	0.95
Feed1,Pol1	23	1.21
Feed2,Pol0	21	1.11
Feed2,Pol1	19	1.00
Feed3,Pol0	15	0.79
Feed3,Pol1	50	2.63
Feed4,Pol0	303	15.95
Feed4,Pol1	17	0.89
Feed5,Pol0	-9999	-526.26
Feed5,Pol1	39	2.05
Feed6,Pol0	17	0.89
Feed6,Pol1	138	7.26

The second column indicates the RMS of the calibrator map (using 3c147). The third column indicates the sensibility ratio of each channel with respect to the Right channel of the second feed (which is stable). Channel 5,Pol0 (Left) is not usable.

Future receivers: the SRT was designed to accommodate up to 20 receivers. A 7-feed S-band receiver (3 – 4.5 GHz) is undergoing testing and designed to be placed at the primary focus of the telescope (requiring the parabolic configuration). The receiver had its first light in November 2016 (for its central feed). The full commissioning of this receiver is expected to end in 2021. Additionally, a number of high-energy receivers are being planned for the SRT. This includes a multi-feed W receiver and a cryocooled, 19-pixel dual-polarized Q-band system at the secondary/Gregorian focus.

More details about current and future receivers at Italian radio telescopes (SRT, Medicina and Noto) are included in this review document: [receivers](#)

## 3.1 LP-band Filters

Different RF filters are available for the LP-band receiver. Although it is a coaxial receiver package, the control system sees it as a group of three different receivers, each one with its own code:

For the PPP receiver (P-band), there is one available filter (with code L2XX for linear or C2XX for circular): 300–360 MHz (which is needed to exclude RFI at higher frequencies).

For the LLP (L-band) configuration, the following filters are available for linear or circular polarizations:

- XXL1 (for linear) or XXC1 (for circular): all band, 1300–1800 MHz (no filter) (not recommended)
- XXL2 (for linear) or XXC2 (for circular): 1320–1780 MHz
- XXL3 (for linear) or XXC3 (for circular): 1350–1450 MHz (VLBI band)
- XXL4 (for linear) or XXC4 (for circular): 1300–1800 MHz (band-pass)
- XXL5 (for linear) or XXC5 (for circular): 1625–1715 MHz (VLBI band)

For simultaneous LP observations, all combinations of the above configurations are allowed.



# CHAPTER 4

## Backends

The frontend (receiver) outputs are connected to the backend instruments either by coaxial cables or optical fibers, depending on whether the backend is located in the main building or below the dish. The following backends, designed for specific scientific activities, are available at the site:

These backends are available for the current call for proposals:

Backend	Bands	Bandwidth (MHz)	Sampling time	Max freq. bins	Observing modes
<b>Total Power</b>	C,K	250,680,1200,2000	1-1000 ms	1	continuum (analog)
<b>XARCOS</b>	C,K	0.5,2.0,7.8,62.5	10s	2048	spectro-polarimeter
<b>SARDARA</b>	C,K	420(300*),1500(1200*)	down to 5ms	1024 or 16384	spectro-polarimeter(*)
<b>SARDARA</b>	L	420(90/100*),1500(500*)	down to 5ms	1024 or 16384	spectro-polarimeter(*)
<b>DFB3</b>	L,C,K	256,512,1024	100 microsec	8192, pulsars: 2048	online pulsar folding + pulsar/transient search
<b>ROACH1</b>	P,L,C,K	128	.	(varies)	baseband recorder + offline pulsar folding + pulsar/transient search
<b>DBBC</b>	P,L,C,K	512	.	.	VLBI

(\*) For the 1500 MHz SARDARA configuration, the actual available RF bandwidth is 1200 MHz with the C-band and K-band receivers. Similarly, for the 420 MHz SARDARA configuration, the effective RF bandwidth is 300 MHz with the K-band and C-band receivers. Instead, the L-band receiver only has 500 MHz of RF bandwidth; when the

SARDARA 420 MHz configuration is needed, the actual available RF bandwidth for SARDARA is 100 MHz (when selecting the XXL3 or XXC3 filters) or 90 MHz (when selecting the XXL5 or XXC5 filters).

## 4.1 Total Power

The Total Power backend is a single-band, seven-beam backend for continuum observations. Located just below the dish, this backend is formed by 14 voltage-to-frequency converters that digitize the incoming RF signals. Different IF inputs can be selected from three focal points. Different bandwidths (maximum bandwidth: 0.1 - 2.1 GHz) and attenuation levels can be selected.

This backend consists of 14 sections. Each section processes a single IF channel with a single polarization, as input. The signal is detected by a broadband square-law detector and then digitized by an A/D converter. The nominal IF band is 2 GHz (0.1-2.1 GHz). On-board filters can restrict the band to 250, 680, or 1200 MHz. The same boards also perform the focus selection for the SARDARA backend. Here are the possible configurations of the Total Power backend for different receivers:

Receiver	Sections	Filters (MHz)	Sampling time (ms)
K-band	14	250,680,1200,2000	1 – 1000
C-band	2	250,680,1200,2000	1 – 1000

## 4.2 XARCOS

This is a seven-beam, narrow-band, digital spectro-polarimeter with 8x2 input channels. The working bandwidth is 135-240 MHz and the maximum number of spectral channels is 2x2048 per polarization and per output channel. The instantaneous bandwidth ranges between 0.488 and 62.5 MHz and the maximum effective spectral resolution is ~500 Hz.

XARCOS is a spectro-polarimeter with a maximum bandwidth of 62.5 MHz capable of processing up to 16 IFs, thus fitting the seven-feed dual polarization K-band receiver array SRT is equipped with. Because its dump time is set to 10 seconds, it is not suitable for On-The-Fly (OTF) observations. The observer can select the following configurations:

- XK77, to use the full K-band array; each digital sample has a 6-bit range. Full-Stokes sections are recorded, each having a 62.5MHz bandwidth and 2048(x4) channels.
- XK03, to use the K-band feeds #0 and #3. Each feed outputs two full Stokes sections respectively having bandwidths of 62.5 MHz and 4 MHz and 2048(x4) channels. Each digital sample has an 8-bit range.
- XK06, to use the K-band feeds #0 and #6. Each feed outputs two full Stokes sections respectively having bandwidths of 62.5 MHz and 4 MHz and 2048(x4) channels. Each digital sample has an 8-bit range.
- XK00, to use only the K-band central feed. It outputs four full-Stokes sections respectively with bandwidths of 62.5 MHz, 8 MHz, 2 MHz and 0.5 MHz, each having 2048(x4) channels. Each digital sample has an 8-bit range.
- XC00 , to use the C-band receiver. It outputs four full-Stokes sections respectively with bandwidths of 62.5 MHz, 8 MHz, 2 MHz and 0.5 MHz.

More information about XARCOS configurations can be found here: [Melis et al., OAC Internal report N. 52](#).

It is worth noting that, given a particular configuration (e.g. XK00), the sections are obtained simultaneously. For each section, the bandwidth and starting frequency can then be set. For more information about this procedure, see [XARCOS](#).

Notes:

- XARCOS has been tested in circular polarization. Linear polarization observations are also admitted but in shared-risk mode. The full-Stokes configuration is therefore in shared-risk mode. Please contact the antenna staff.
- At C-band, standing waves have been identified that affect observations for  $T_{\text{continuum}}/T_{\text{sys}} > 0.05$  (value to be confirmed).

### 4.3 Digital Base Band Converter (DBBC)

This digital platform is based on a flexible architecture composed of four ADC boards, with 1 GHz of bandwidth each and four Xilinx FPGA boards for data processing. The platform is designed mainly for VLBI experiments; however, a wideband spectrometer has been developed for other purposes.

### 4.4 Digital Filter Bank mark 3 (DFB3)

This is an FX correlator developed by the Australia Telescope National Facility (ATNF) that performs full-Stokes observations. It allows for four inputs, each with a 1024 MHz maximum bandwidth and 8-bit sampling for a high dynamic range. The DFB3 is suitable for precise pulsar timing and searching. It allows for up to 8192 spectral channels in order to counter the effects of interstellar dispersion.

The available configurations for pulsar observations are the following:

Obs type	Nbins	BW(MHz)	Nfreq
folding	1024	1024	2048
folding	1024	1024	1024
folding	1024	1024	512
folding	1024	512	2048
folding	1024	512	1024
folding	1024	512	512
folding	512	1024	1024
folding	512	512	2048
folding	512	512	1024
folding	512	512	512
folding	512	256	512
folding	512	128	2048
folding	256	256	2048
folding	256	64	2048
folding	256	64	1024(*)
search		1024	1024
search		1024	512
search		512	1024
search		512	512
search		512	128

(\*) This configuration does not work for pulsars with periods  $< 1.6$  ms.

- Choosing the best folding configuration depends in part on the period of the pulsar. One can find the best folding configuration for a range of folding periods [here](#).
- These search mode configurations have been successfully tested for the acquisition of total intensity data ( $n_{\text{pol}}=1$ ) for sampling times down to 100 microseconds. Full Stokes data can be obtained only with slow sampling times ( $\geq 512$  microsec for 1024 channels over 512 MHz of bandwidth and  $\geq 256$  microsec for 512 channels).

Further details about the DFB can be found in the ATNF [DFB manual](#).

At the SRT, DFB observations are piloted using the SEADAS software.

## 4.5 ROACH1

*The use of this backend is admitted in shared-risk mode. Users are required to contact the antenna staff prior to submission, in order to assess the availability of software/hardware services for their specific needs.*

The ROACH1 (or ROACH) backend is an FPGA board developed by the CASPER collaboration, with two ADC converters and a reprogrammable architecture. It can be used to acquire **baseband data** (voltages) or for **real-time folding of pulsar data**, thanks to the PSRDADA software. The currently available bandwidth is 128 MHz using a CPU cluster with 8 nodes (each node processes 16 MHz, so 8 x 16 MHz in total).

The ROACH1 backend has been the backend of choice for the Large European Array for Pulsars (LEAP) project. More information on the implementation of the LEAP project with the ROACH1 backend can be found here: [OAC Internal Report N. 39](#). It is also used to perform all P-band pulsar observations at SRT. Its ability to perform coherent de-dispersion makes it a superior backend compared to the DFB. Its 128 MHz of available bandwidth (only 128 MHz of its 512 MHz capability is currently available because of the limited number of installed CPU nodes) is largely sufficient for P-band but more limited for L-band. In the near future, access to GPU nodes will increase the available bandwidth to 512 MHz.

Note: for the current call for proposals, no real-time folding of data will be performed for pulsar observations with this backend. The data will be acquired in baseband mode and folded offline during the data post-processing. The final data output will be made available by antenna staff after a few hours or days.

## 4.6 SARDARA

*The use of this backend is admitted in shared-risk mode. Users are required to contact the antenna staff prior to submission, in order to assess the availability of software/hardware services for their specific needs.*

The SARDARA backend is composed of seven fully-reconfigurable ROACH-2 boards that allow it to perform wide-band spectro-polarimetric observations. The many observing modes covered by SARDARA include: continuum, spectroscopy and spectro-polarimetry. In the future, it will also be able to perform high-time resolution for pulsars and fast transients (not currently available). Its sampling time can be set from 5ms to 1 s. It is the backend of choice for On-The-Fly (OTF) spectro-polarimetric observations. Available configurations consist of:

### in C and K bands:

- 420 MHz bandwidth with 1024 or 16384 channels
- 1500 MHz bandwidth with 1024 or 16384 channels

SARDARA's spectral resolution and sensitivity are defined by its full 1500 MHz bandwidth. However only 1200 MHz of the full 1500 MHz bandwidth is usable, since the 1200 MHz filter of the Total Power backend's Focus Selector is being used as input to SARDARA.

### L-band setup

The full bandwidth for this receiver is 500 MHz (1.3-1.8 GHz). RF filters must be used (choose between XXL4, XXL2 etc.). For the 420 MHz configuration, the available filters are: XXL3, XXL5, XXC3 and XXC5 (to be selected following the needed sky frequency and polarization). We note that with these filters, the effective RF bandwidth is 100 MHz (using the XXL3 or XXC3 filters) or 90 MHz (using the XXL5 or XXC5 filters).

**SARDARA is offered in shared-risk mode in all of its configurations.**

More detailed information on the SARDARA backend can be found here: [SARDARA](#).



## 5.1 Pointing model

This calibration procedure was used to calculate the pointing errors in ideal conditions, i.e. at night without sunlight. Actual conditions will most likely require new pointing measurements in order to take into account possible errors due to environmental factors. Pointing measurements before starting an observing session are highly recommended and can be included in the observation schedule.

In the table below, we report the calculated rms values in ideal conditions:

Parameter	Value (deg) for L-band	Value (deg) for C-band	Value (deg) for K-band
Az-mean		+0.000440	+0.000850
Az-rms	+0.001944(*)	+0.000790	+0.000870
El-mean		-0.001660	-0.001280
El-rms	+0.001944(*)	+0.000910	+0.001200

(\*) values for L-band from Bolli et al (2015)

## 5.2 Focus curve calibration

The focus curve is applied in real time. However, it is highly recommended that for C and K-band observations, the observer perform a focus calibration before starting an observing session.

## 5.3 Gain curve calibration

From the measured gain curves (Gain vs. Elevation), one fits a 2-degree polynomial with the parameters C0, C1 and C2:

$$\text{gain (K/Jy)} = C2 \text{ El}^2 + C1 \text{ El} + C0$$

Parameter	Value (L-band)	Value (C-band)	Value (K-band)
C0	0.5061	0.545439	0.364897
C1	0.002390	0.00525597	0.00624137
C2	-0.000021	-4.55697e-5	-4.60020e-5

L-band: from Orlati et al.

C-band: valid from 2018.

K-band: from Prandoni et al. (2017). The DPFU is 0.60 K/Jy.

## 5.4 Beam shape

In the following tables, the second lobe and third lobe percentages correspond to the contribution of the counts in that lobe as compared to the central beam.

- C-band

Elevation range (deg)	Second lobe (%)	Third lobe (%)
15-25	1.7	0.65
25-35	1.7	0.42
35-50	1.4	0.41
50-65	1.0	0.41
65-75	1.5	0.43
75-85	2.0	0.40

- K-band

Elevation range (deg)	Second lobe (%)	Third lobe (%)
20-40	11	0.6
40-60	4.9	0.5
60-80	3.4	0.5

## 5.5 List of calibrators

Here is a list of useful calibrators for various types of calibration:

Flux	Polarization angle	Instrumental polarization
3C286	3C286	3C84
3C147	3C138	NGC7027
3C48		
3C295		

For pointing calibration, see below in “Useful links”.

## 5.6 Derotator alignment

The derotator has been aligned within 1-2 arcseconds.

## CHAPTER 6

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### Data quicklook

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Information about a data quicklook will be inserted here very soon.



### **7.1 Conversion of data acquired in spectroscopic mode**

Conversion to the GILDAS data format is provided for data acquired in Nodding and Position Switching modes with the SARDARA and XARCOS backends, including spectra containing the signal from the noise diode (when used).



## CHAPTER 8

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### Useful links

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A general description of the SRT, including technical commissioning information and first light results, can be found in the technical commissioning paper: [Bolli et. al, Journal of Astronomical Instrumentation, Vol. 4, Nos. 3 & 4 \(2015\) 1550008.](#)

Scientific tests and applications for the SRT are described in the following scientific validation paper: [Prandoni et. al, A&A 608, A40 \(2017\).](#)

Science done with SRT during its early-science run (2016) with the various hardware and software described below can be found here: [Science with SRT.](#)

Spectral-polarimetric techniques with SRT: [Sardinia Radio Telescope wide-band spectral-polarimetric observations of the galaxy cluster 3C 129.](#)

ROACH1 backend for baseband data recording and pulsar observations: [OAC Internal Report N. 39.](#)

SARDARA backend description: [SARDARA.](#)

Gain curve calibration at L-band: [Orlati et al..](#)

Pointing calibration: [Tarchi et al. \(2013\) OAC Internal Report N. 27.](#)

[Ricci et al., “A first extended catalogue of pointing/focus calibrators for the Sardinia Radio Telescope”.](#)





## CHAPTER 9

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### User guide and observing modes

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Instructions for observing at the SRT with different modalities (receivers, backends, modes) are provided here: [instructions](#)

A complete manual about the Italian radio antennas is found here: [DISCOS](#).



## CHAPTER 10

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### Observing tools

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Source visibilities can be determined using the [CASTIA online tool](#).

The online Exposure Time Calculator (ETC) can be found here: [ETC tool](#).



# CHAPTER 11

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## Indices and tables

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- `genindex`
- `modindex`
- `search`