THE DLR AIRBORNE EXPERIMENTAL SAR SYSTEM - E-SAR

Ralf Horn, Joao Moreira, Hans-Jürgen Müller, Franz Witte

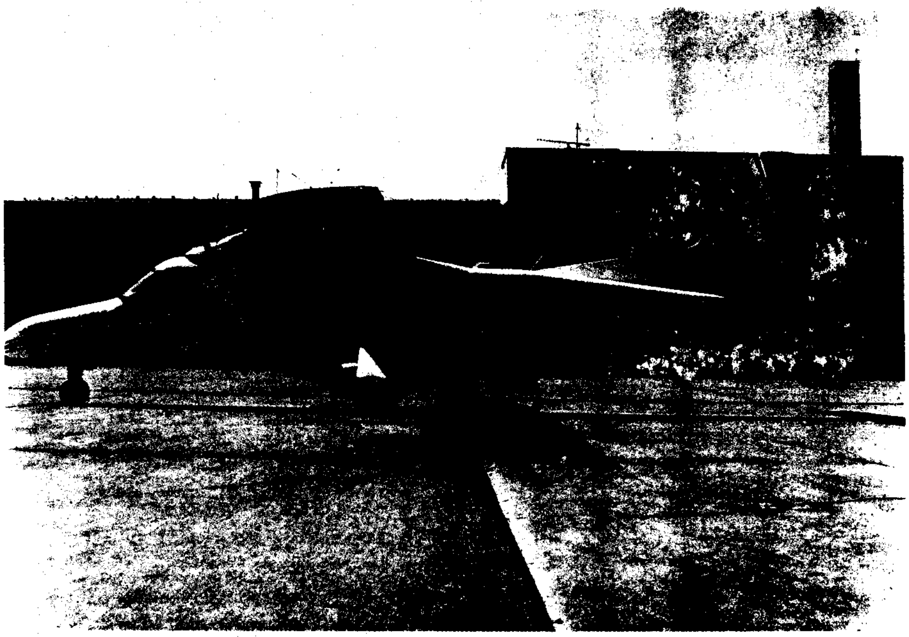
German Aerospace Research Establishment (DLR)
Institute for Radio Frequency Technology
D-8031 Oberpfaffenhofen, Germany

Ulf Palme

Instituto de Pesquisas Espaciais, INPE
Departamento de Sensores
Sao José dos Campos, Brazil

DLR Oberpfaffenhofen Research Centre and Oberpfaffenhofen airfield. E-SAR overflight on April 6, 1989, in C-Band, vertical polarization. Data processed by DLR.

Introduction. The DLR airborne experimental synthetic aperture radar (SAR) system E-SAR, designed and manufactured at the DLR Institut fuer Hochfrequenztechnik, is a research tool to elaborate SAR related problems concerning both system performance and data analysis. The instrument is installed on board a DLR Dornier DO 228 aircraft, which is a small STOL aircraft (STOL: **s**hort **t**ake-**o**ff and **l**anding), offering the advantages of low costs and operation from airstrips in any part of the world.



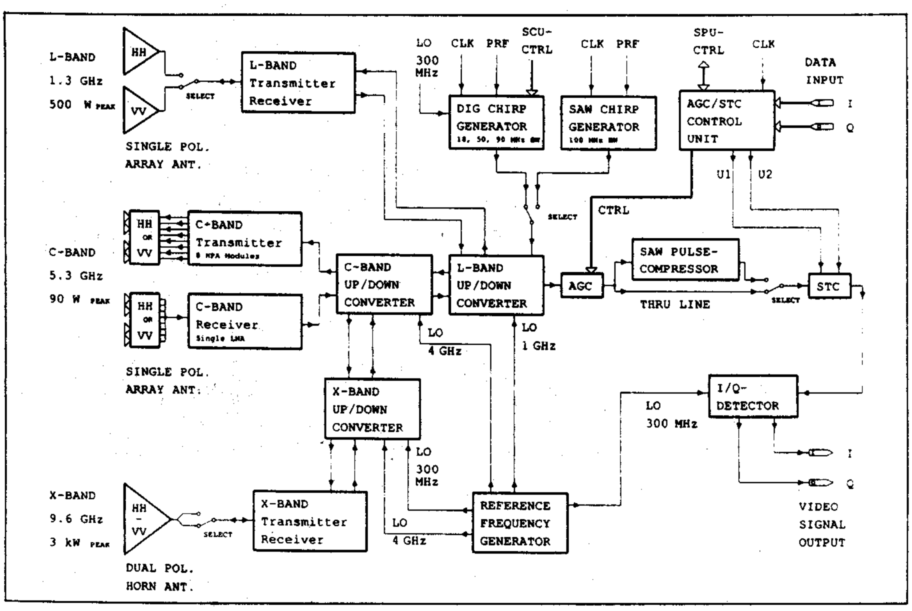
DLR research aircraft DO 228 equipped with the E-SAR radar sensor. Antenna installation visible beneath cargo door.

Since the beginning of 1989 the E-SAR system has been flown many times in preparatory campaigns for the European Remote Sensing Satellite ERS-1. The German/Italian X-SAR, which will fly with SIR-C on three Shuttle Radar Lab missions, and the French Radar 2000, both spaceborne SAR projects, are supported with E-SAR image data.

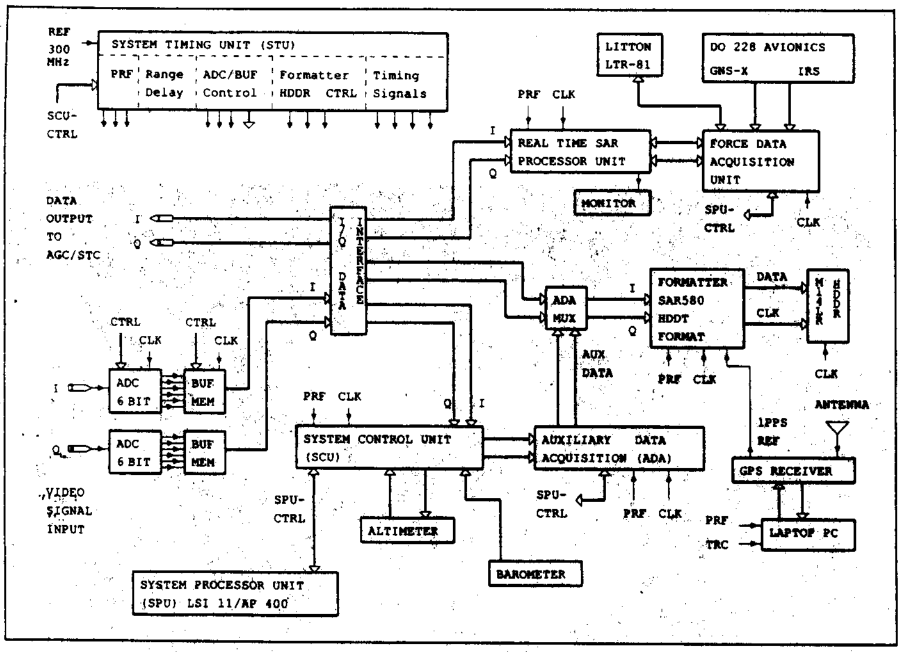
Applications. The E-SAR is a high-resolution SAR operating in L-, C- and X-band with either horizontal or vertical polarization. Although being developed mainly for use by the research community, commercial lease opportunities are as well anticipated. The sensor is versatile, with many options for flight and radar configurations and image products. It provides the opportunity to image areas, wether flat or mountaineous terrain, ocean or ice, with excellent image quality. It can be used for monitoring resources, renewable such as agriculture and forestry, or nonrenewable such as geological resources. Changing characteristics such as urban growth, deforestation or ocean waves also can be monitored.

E-SAR sensor hardware mounted in standard flight racks to be installed on board the aircraft.

The System Platform. A Dornier DO 228 aircraft equipped with modern navigation systems like a laser **i**nertial **r**eference **s**ystem (IRS) and a GPS receiver carries the E-SAR sensor. Its maximum take-off weight equals 5980 kg. The maximum operating altitude above **m**ean **s**ea **l**evel (MSL) is 8000 m. The maximum cruising speed is about 440 km/h. For SAR operation the nominal ground speed of the aircraft is 70 m/s, which corresponds to 252 km/h.



E-SAR sensor system blockdiagram. (RF-electronics)



E-SAR sensor system blockdiagram. (Digital electronics)

The On-board Segment. The radar sensor is a modular designed system, which contains three different RF-segments in L-, C- and X-band. Pulse generation and I/Q-detection are located in the IF-section. A single digital conversion and recording system is used to store the SAR raw data on high density digital tape (HDDT) formatted in the SAR 580 HDDT format.

The On-ground Segment. The ground segment consists of the following units:

- **Radar Raw Data Transkription.** A SAR 580 High Density Tape Transcription system (HTS) transcribes the raw data from HDDT to computer compatible EXABYTE (Video 8) tapes. A further data transfer to conventional CCTs is possible. This operation also converts the SAR 580 HDDT format into the SAR 580 video signal CCT format and provides the full data rate in a single channel transcription mode.
- **E-SAR Standard SAR Processing.** The E-SAR standard SAR processor consists of three basic modules, auxiliary data processing, off-line motion compensation and focused multi-look SAR processing. The development was carried out in DLR. The processor output is calibrated and available in form of a standard image product.

Motion Compensation. The DO 228 aircraft is fairly sensitive to air turbulence and therefore not very well suited for carrying a SAR sensor. A SAR is a coherent system and flight instability causes phase errors, which, in turn, defocus and distort the image geometrically. This problem can be overcome by measuring the dynamic behaviour of the platform and correcting the SAR data, either on board the aircraft or on ground. Two methods for compensating platform motions are implemented with the E-SAR, one using an Inertial Measurement Unit (IMU), the other, the "Reflectivity Displacement Method (RDM)", extracting true forward velocity and Line-of-Sight (LOS) accelerations out of the radar raw data. This guarantees that the E-SAR achieves good image quality with high spatial and radiometric resolution.

E-SAR Technical Specifications.

RF centre frequency, L-band:	1.3	GHz
C-band:	5.3	GHz
X-band:	9.6	GHz
IF centre frequency:	300	MHz
System bandwidth:	120	MHz
SAW chirp, signal bandwidth:	100	MHz
expanded pulse length:	4.98	μsec
compressed (analogue) pulse length:	17	nsec
Digital chirp, signal bandwidth, narrow swath mode:	90	MHz
wide swath mode:	50	MHz
super wide swath mode:	18	MHz
expanded pulse length:	5.0	μsec
Antenna gain, L-band:	14	dBi
C-band:	17	dBi
X-band:	17.5	dBi
Antenna 3 dB beamwidth, azimuth, L-band:	18	Deg
C-band:	19	Deg
X-band:	17	Deg
elevation, L-band:	35	Deg
C-band:	33	Deg
X-band:	30	Deg
Transmit peak power, L-band:	500	W
C-band:	90	W
X-band:	2500	W
Receiver noise figure, L-band:	8.5	dB
C-band:	4.0	dB
X-band:	4.5	dB
Receiver dynamic range with AGC/STC:	≥ 40	dB
Nominal pulse repetition frequency (PRF):	952.38	Hz
Variable PRF range:	+/– 30	%
Quantization (I or Q):	6	bit
A/D converter dynamic range (at 35 MHz):	25	dB
Sampling rate, narrow swath mode:	100	MHz
wide swath mode:	60	MHz
super wide swath mode:	20	MHz
Echo buffer memory capacity (I or Q):	2560	words
Nominal data rate on high density tape:	28	MBPS
Maximum recording time per tape (14 inch tape reel):	15	min

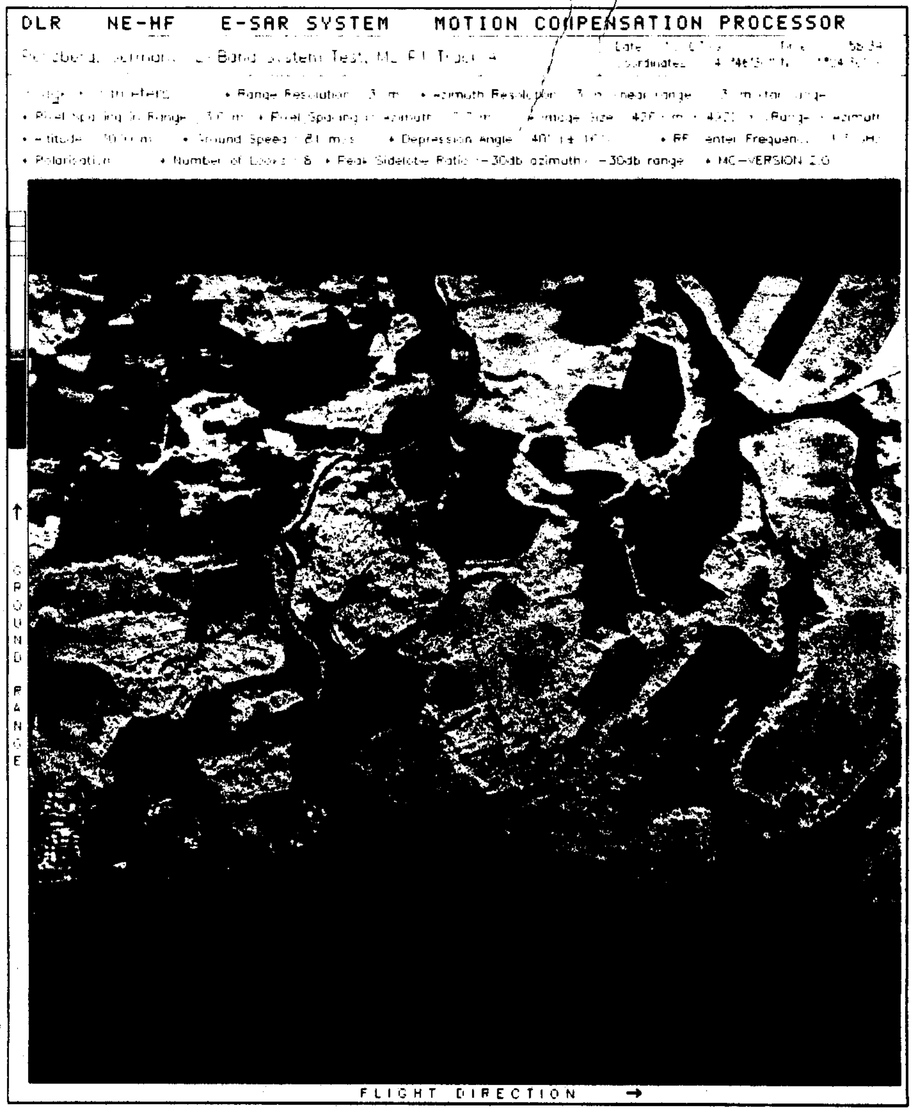
E-SAR Standard Image Quality Specifications.

Spatial resolution, range and azimuth, narrow swath mode:	2.5 m x 2.5 m
wide swath mode:	4.5 m x 4.5 m
super wide swath mode:	11.5 m x 11.5 m
Number of statistically independent looks:	8
Radiometric resolution (8 looks):	< 2 dB
Geometric distortion:	less than one resolution cell

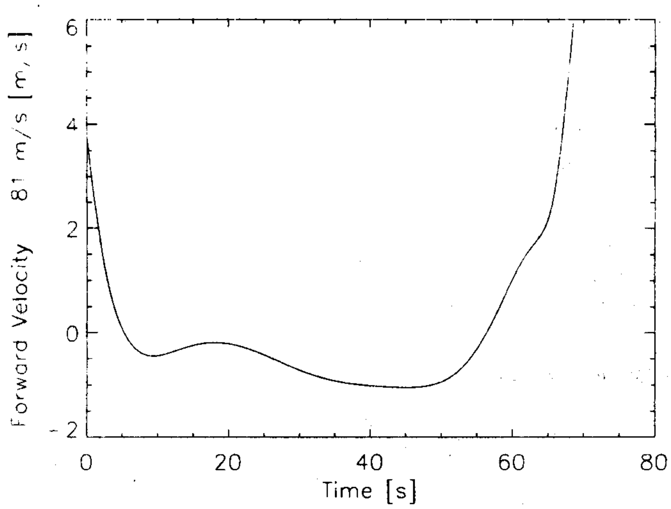
System Features. The E-SAR sensor system offers many features:

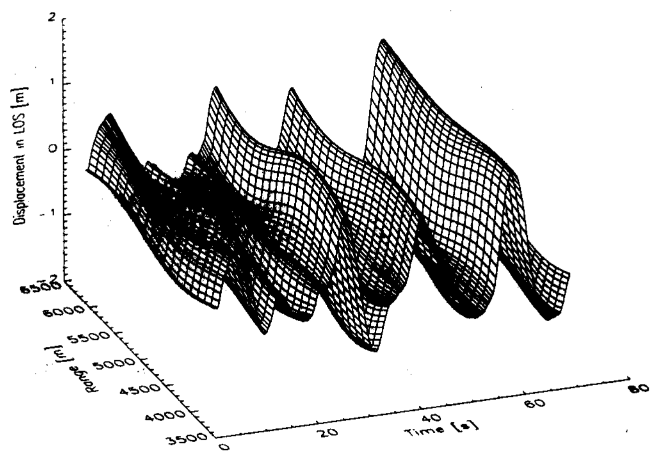
- single channel operation in L-, C- and X-Band with either horizontal or vertical polarisation, mode can be changed from pass to pass,
- a platform inertial attitude and heading measurement unit for calibration and off-line motion compensation, data are recorded on EXABYTE tapes,
- selectable swath modes, narrow swath (3 km width in slant range), wide swath (5 km) or super wide swath (15 km),
- on-board real time SAR "quick-look" processing, data recording on EXABYTE tapes and image monitoring,
- range dependent variable receiver gain using an adaptive AGC/STC control system,
- a differential GPS measurement system for accurate aircraft tracking,
- built-in test equipment for sensor system internal testing and calibration.

Operating Geometry. The radar is capable of mapping in three different swath modes: narrow, wide and super wide swath. The aircraft altitude for operation of the SAR is variable and ranges from 1000 m above ground to 5000 m above mean sea level. Optimum is 3500 m (MSL). The depression angles of the antennas can be varied either mechanically (C- and X-Band) or electronically (L-Band) within a range of 20° to 50°. The off-nadir angles typically range from 15° to 70°. High performance imagery of flat terrain can be obtained in the narrow swath mode up to a maximum slant range distance of 7000 m. This limit is given by the low transmitter RF output power in C-Band. The slant range swath width is determined by the number of complex (I and Q) samples (2048) and the range sample spacing (narrow swath: 1.5 m, wide swath: 2.5 m, super wide swath: 7.5 m). E-SAR sensor operation in wide and super wide swath coincides with accordingly reduced spatial resolution.



E-SAR L-Band image, 8 looks, 3 m x 3 m resolution, recorded on July 10, 1991. The site is located near the town of Penzberg in Southern Germany. The river Loisach is a main feature in this image.





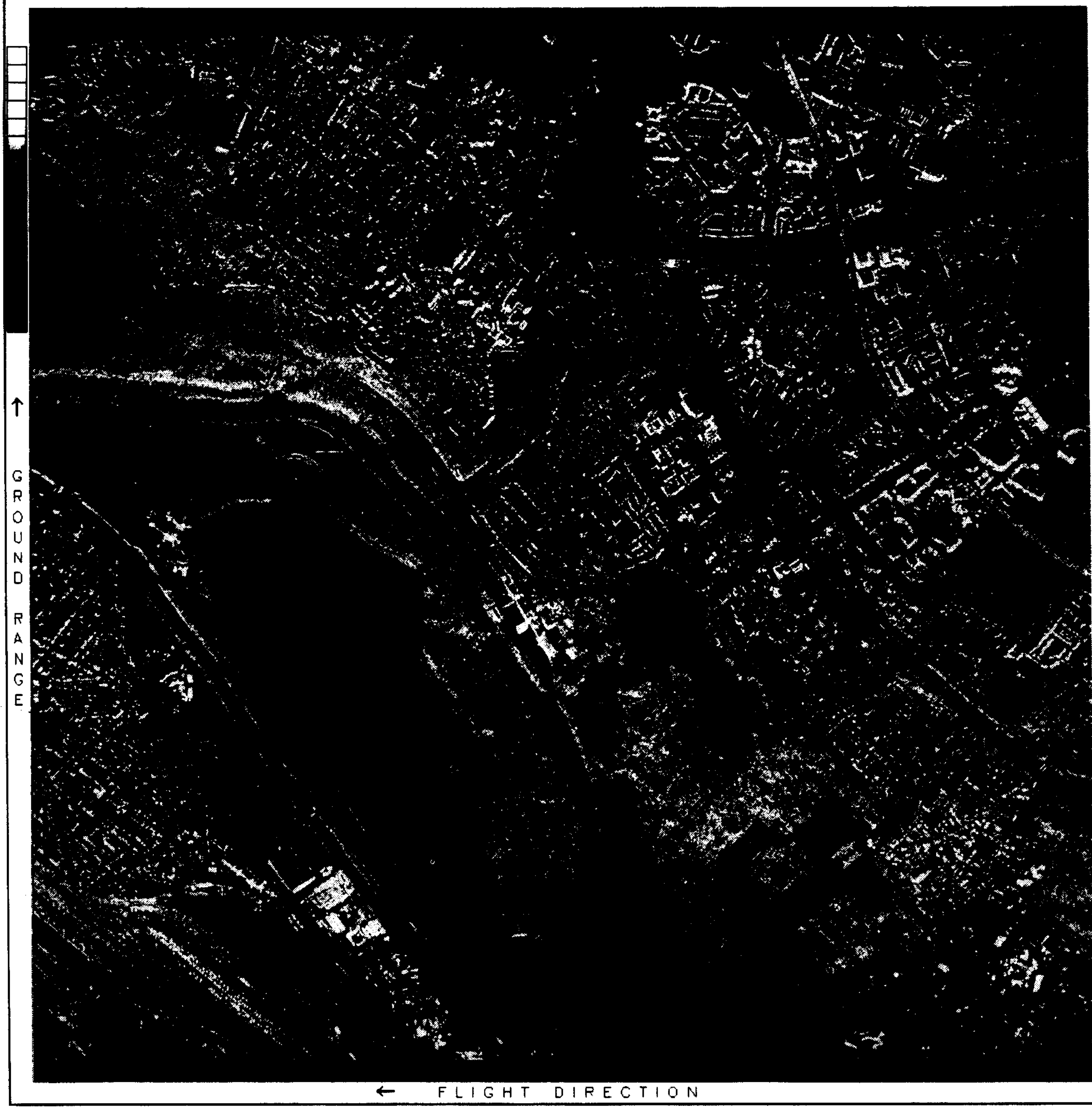
Forward velocity and displacement in Line-of-sight (LOS) extracted by "RDM"-Motion Compensation. Data were used to focus the L-Band image shown above.

DLR NE-HF E-SAR SYSTEM MOTION COMPENSATION PROCESSOR

Marne la Valle CARAF, M2P5, Track 1

Date > 05-12-89 Time > 14:13:40
Coordinates > 48°51'54" N 02°34'30" E

Image Parameters > * Range Resolution : 3. m * Azimuth Resolution : 3. m (near range) / 3. m (far range)
* Pixel Spacing in Range : 1.5 m * Pixel Spacing in Azimuth : 1.5 m * Image Size : 3501 m X 3663 m (Range X Azimuth)
* Altitude : 3500 m * Ground Speed : 68 m/s * Depression Angle : 45° (± 17°) * RF Center Frequency : 9.6 GHz
* Polarisation V V * Number of Looks : 8 * Peak Sidelobe Ratio :-30db azimuth/ -30db range * MC-VERSION 1.8



E-SAR X-Band image, 8 looks, 3 m x 3 m resolution, recorded on December 5, 1989. The site is located east of Paris, France, and shows the suburb Marne la Vallée and the river Marne. (Courtesy CNES)