2.2 *Properties of sources*

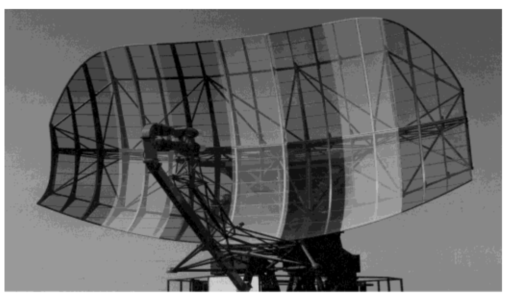
1. Power density, coverage and waveform
2. Evaluation of sources
3. Digital vs analogue

Properties of illuminators of opportunity

power density at target	coverage	waveform
▪ $\Phi = \dfrac{P_T G_T}{4\pi R_T^2}$ ▪ vertical-plane coverage	▪ spatial coverage ▪ temporal coverage ▪ revisit time ▪ number and spacing of txs ▪ geometry: forward scatter ?	▪ frequency ▪ bandwidth ▪ ambiguity function ▪ presence of CW carrier

Existing radars (terrestrial, naval, airborne ...)

- plenty – for ATC, long range air defence, AEW, etc.
- in general will scan in azimuth – hence synchronization and pulse chasing necessary
- waveform and Φ very favourable

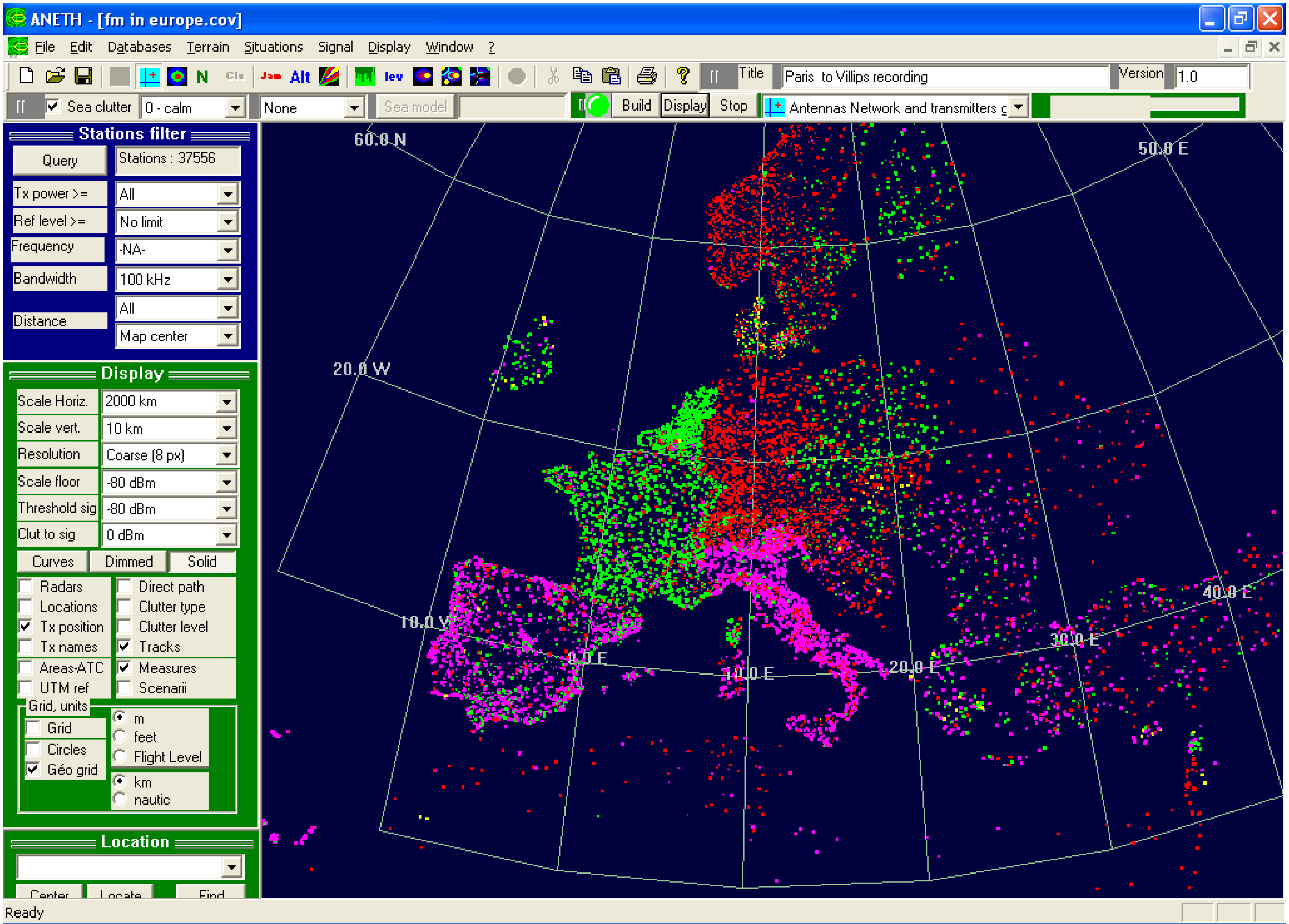


FM radio

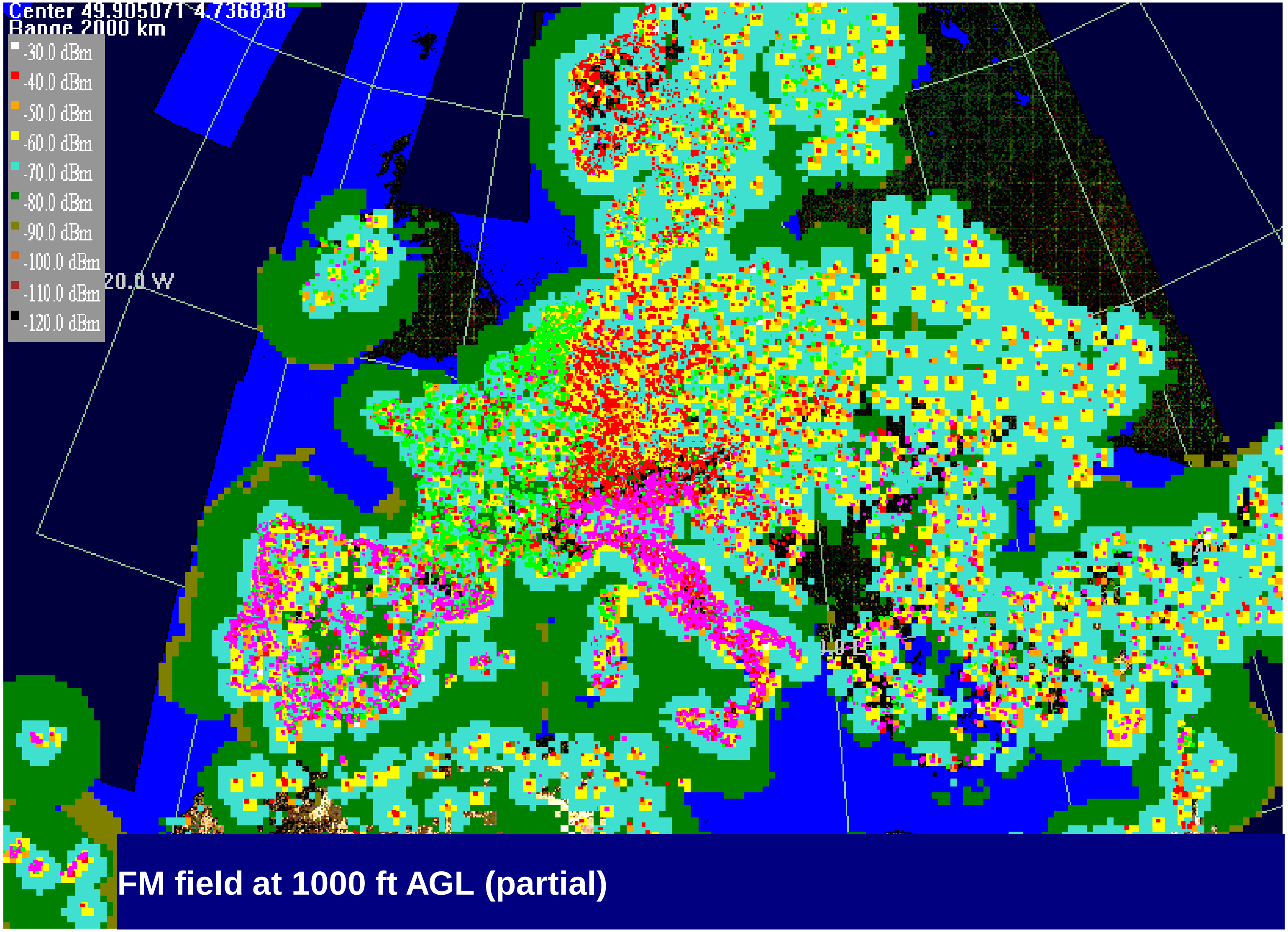
- VHF (~100 MHz), bandwidth ~50 kHz (c/2B = 3000 m); typically 4 channels per transmitter covering 10 MHz total
- broadband FM
- highest power transmitters in UK are 250 kW EIRP; many others of lower power
- 250 kW EIRP gives $\Phi = -57$ dBW/m^2 @ 100 km
- omnidirectional in azimuth; vertical-plane radiation pattern shaped to avoid wasting power above horizontal

http://www.bbc.co.uk/reception/

FM transmitter density: Europe



FM field: Europe

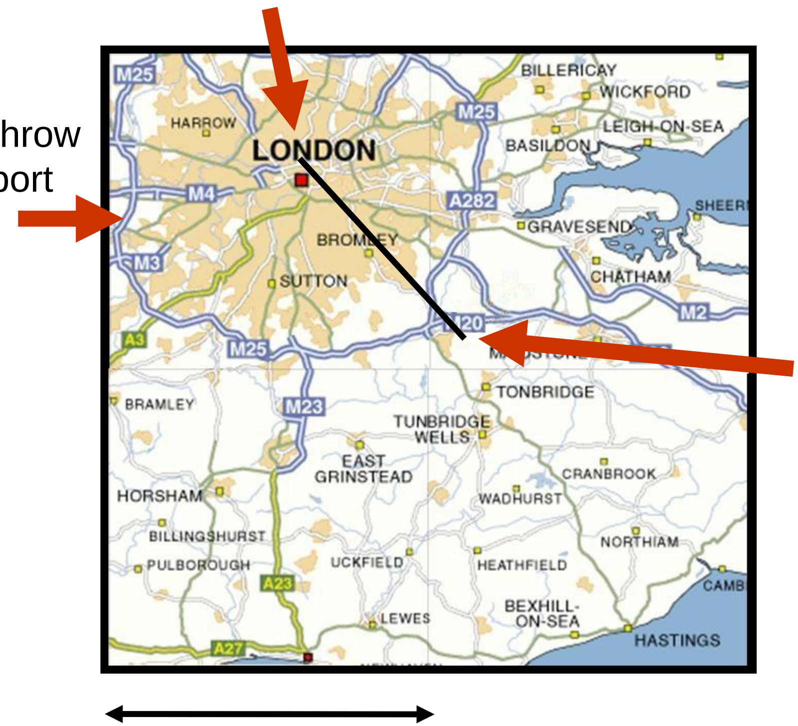


FM field at 1000 ft AGL (partial)

Forward scatter VHF FM

- BBC Radio 4, 93.5 MHz, Wrotham (Kent)
- aircraft target on approach to Heathrow, crossing baseline
- receiver located so that direct signal is weak, hence beat between direct signal and Doppler-shifted echo has maximum modulation
- Doppler shift goes through zero as target crosses baseline

bistatic receiver



Heathrow airport

VHF FM transmitter Wrotham 93.5 MHz

50 km

Forward scatter fences

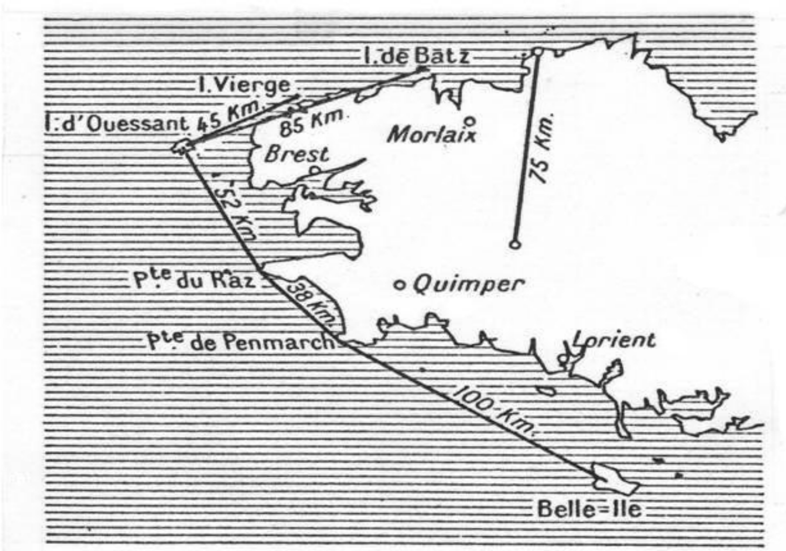
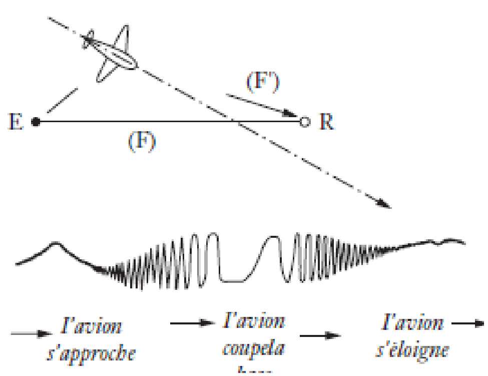


Fig. 1. — « Barrages électromagnétiques » protégeant Brest en 1939



Six of Pierre David's 30 MHz radar fences deployed around Brest in 1939.

It is not clear why two gaps remained. Note the near parallel fences in the northwest coverage, which suggest partial elements of his more complex configuration called the *maille en Z*. It could generate course and speed estimates for non-maneuvering aircraft.

Pierre David, *Le Radar*, PUK Coll. Que sais-je? No. 381, 1969.

Analysis

Take v = 100 m/s

λ= 3 m

d = 30 m

A = 50 m^2

R_R = 5 km

$$\frac{P_R}{P_N} = \frac{P_T G_T}{4\pi R_T^2} . \sigma_b . \frac{1}{4\pi R_R^2} . \frac{G_R \lambda^2}{4\pi} . L_p . \frac{1}{kT_0 BF}$$

$$= \frac{P_T G_T G_R \lambda^2 \sigma_b L_p}{(4\pi)^3 R_T^2 R_R^2 kT_0 BF}$$

then σ_{FS} = +35 dBm^2

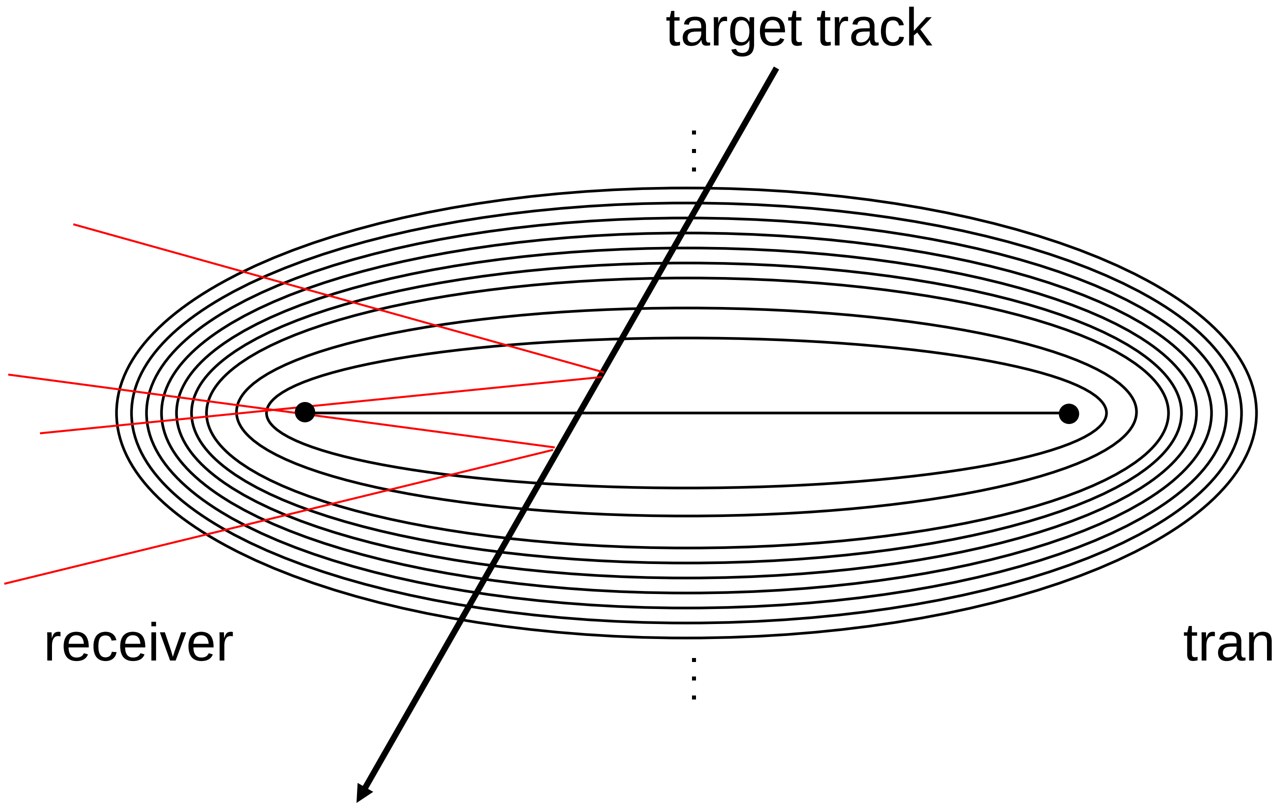
P_R = 8 x 10^{-11} W = –71 dBm

λ/d = 0.1 rad

$t = (R_R \lambda / vd)$ = 5 s

and kT_0B = 8 x 10^{-16} W

Iso-phase contours



each contour represents an extra wavelength in the transmitter-target-receiver path

Terrestrial analog TV

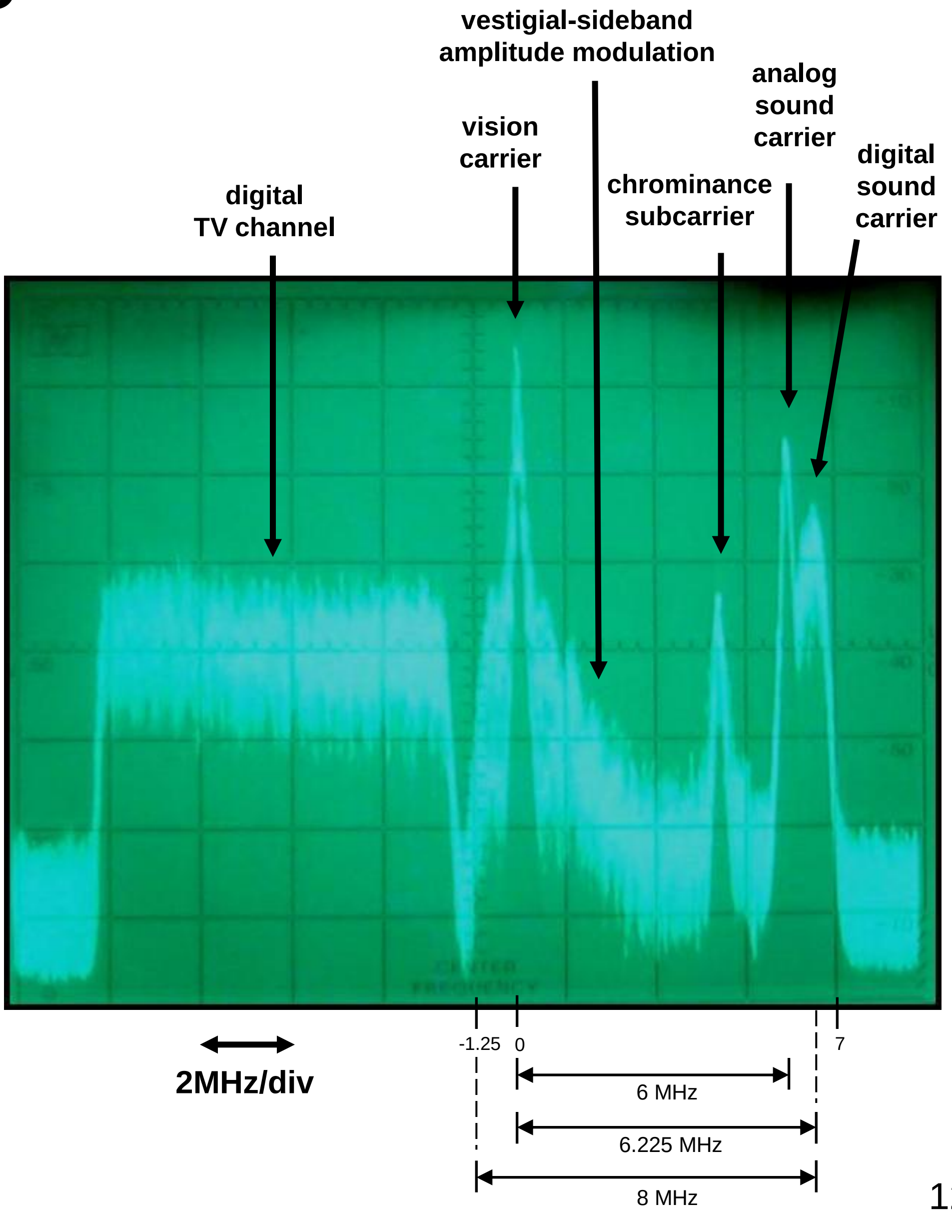
- UHF (~550 MHz), bandwidth of video modulation ~5.5 MHz (c/2B = 30 m)
- vestigial-sideband AM vision; FM sound
- range ambiguities associated with 64μs line repetition rate (≡ 9.6 km)
- highest power transmitters in UK are 1 MW EIRP; many others of lower power
- 1 MW EIRP gives $\Phi = -51$ dBW/m^2 @ 100 km
- omnidirectional in azimuth; vertical-plane radiation pattern shaped to avoid wasting power above horizontal

http://www.bbc.co.uk/reception/

Terrestrial analog TV

measured spectrum of analogue (and digital) TV signals

In the UK the PAL (Phase Alternating Line) modulation format is used, in which the video information is coded as two interlaced scans of a total of 625 lines at a frame rate of 50 Hz. The start of each line is marked with a sync pulse, and the total duration of each line is 64 μs. The video information is modulation onto a carrier as vestigial-sideband AM, coded as *luminance* (Red + Green + Blue) and two *chrominance* signals (Green – Blue) and (Red – Blue). The two chrominance subcarriers are in phase quadrature, so that they can be separately recovered. The sound information (including stereo information) is frequency-modulated onto a second carrier.



Terrestrial analog TV

- UHF (~550 MHz), bandwidth of video modulation ~5.5 MHz
- highest power transmitters in UK are 1 MW EIRP; many others of lower power

Emley Moor is the tallest television mast in England. It has a height of 330 metres and weighs 11,000 tonnes.

Picture courtesy of Dr Stuart Anderson, DSTO

Terrestrial analog TV

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PHYSICS

May Spot Airplanes With Television Receivers

"ENTIRELY possible" is the scientific verdict of radio engineers at the National Bureau of Standards to British dispatches citing the use of television receivers as "spotters" of airplanes.

While Army officials would not confirm reports that similar methods are being worked out for the military uses of the United States, it was admitted that secret research is underway to test other ways of spotting airplanes than by the present sound detection methods.

Since television broadcasts have been in progress over London it has been noted that when airplanes are flying in the vicinity there are produced "ghost" images in the television receivers. These "ghosts" are caused by reflection of the television waves from the metal airplane surface. Thus the reflected waves arrive at the television receivers at a slightly different time than the ordinary waves. The result is a dual image of the scene being transmitted. The image of the plane itself is not received.

According to British reports the displacement of the "ghost" image has been correlated with the distance of the plane away from the television receivers. A system has been worked out whereby television receivers on England's eastern coast could thus serve as "spotters" for approaching enemy aircraft in time of war.

Whether the plan can be worked out in complete detail and serve a valuable military use is for the future to decide, but in principle the method is an almost exact counterpart of the system of determining airplane altitude by having the plane send down to the ground a beam of radio waves and then having the plane pick up the signals of the reflected waves. This method was announced by Dr. E. F. W. Alexanderson of the General Electric Company in 1928.

For the television case, in contrast, the waves go up, strike the plane, and are picked up by ground receivers. By multiple receivers and methods of triangulation it is believed the altitude of the plane and its approximate direction and distance could be worked out.

In another analogy the television spotting system for planes can be called "upside-down" geophysical prospecting. In geology, metallic masses are located by reflected radio waves.

Science News Letter, April 23, 1938

Terrestrial digital TV

- UHF (~746 MHz)
- bandwidth ~6 MHz ($c/2B$ = 30 m)
- typ. 8 kW EIRP (Sutton Coldfield)
- 8 kW EIRP gives $\Phi = -72$ dBW/m^2 @ 100 km
- more noise-like, so would expect ambiguity performance to be better than analogue TV

http://www.bbc.co.uk/reception/

Chinese Mobile Multimedia Broadcasting (CMMB)

- UHF band digital broadcast
- Similar to DVB-T

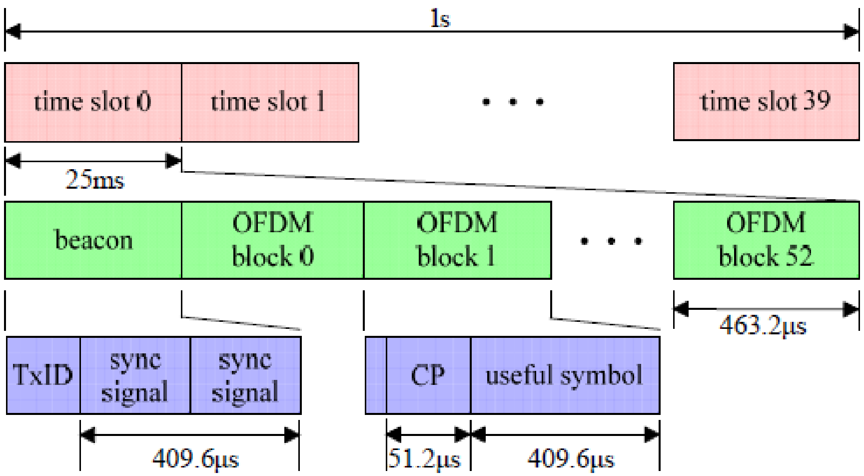
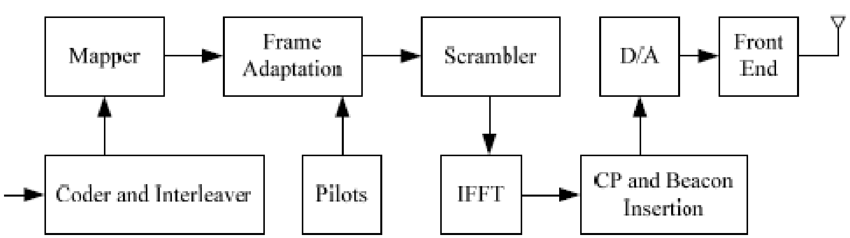
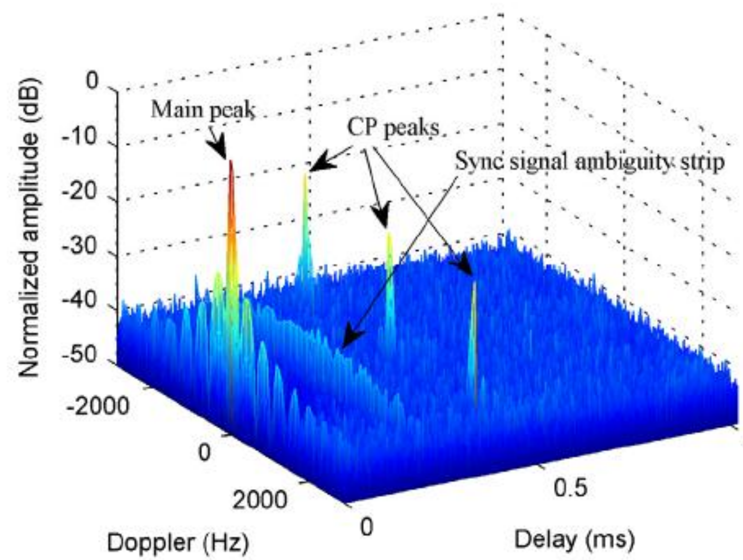


Fig. 1. CMMB frame structure.

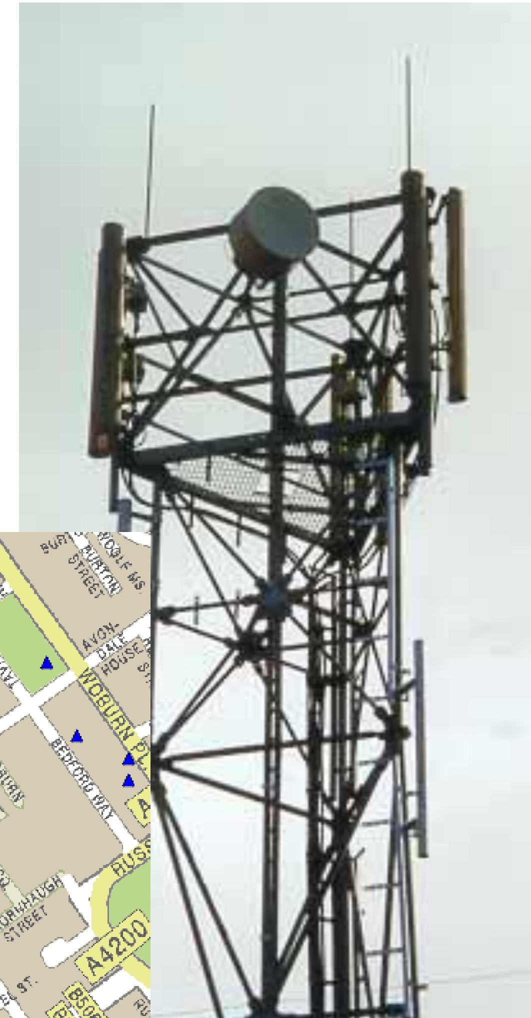
Table Ⅰ CMMB main parameters (8MHz mode)

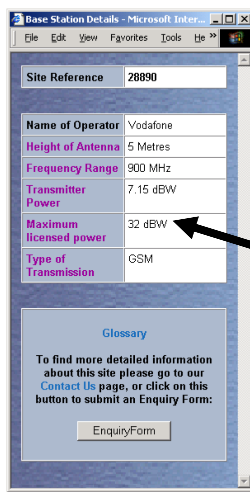
Structures	Useful symbol T_u (μs)	CP T_{cp} (μs)	Valid subcarrier number	Subcarrier interval (kHz)
TxID	25.6	10.4	256	39.0625
Sync signal	204.8	0	2048	4.8828
OFDM block	409.6	51.2	3076	2.4414

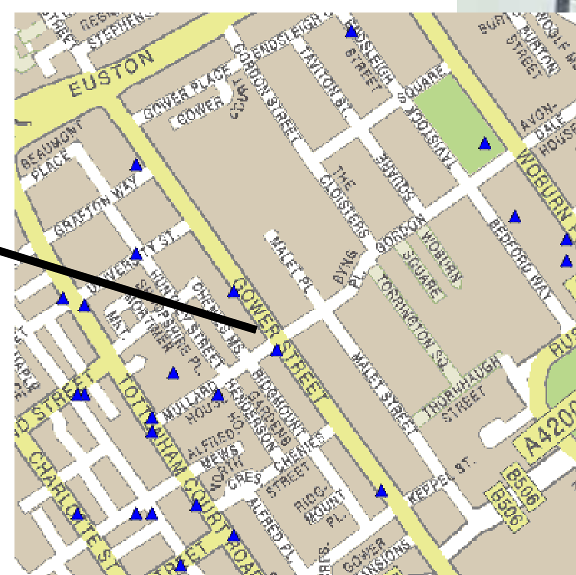




Cellphone basestations

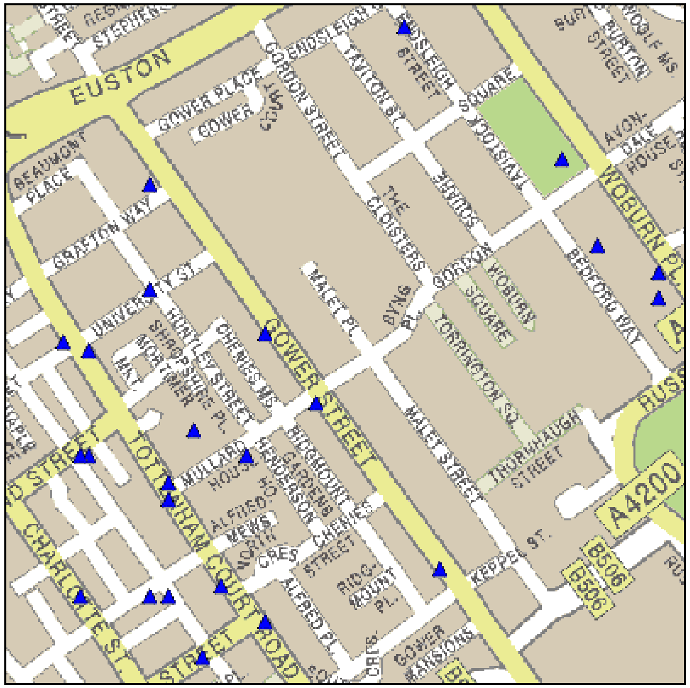




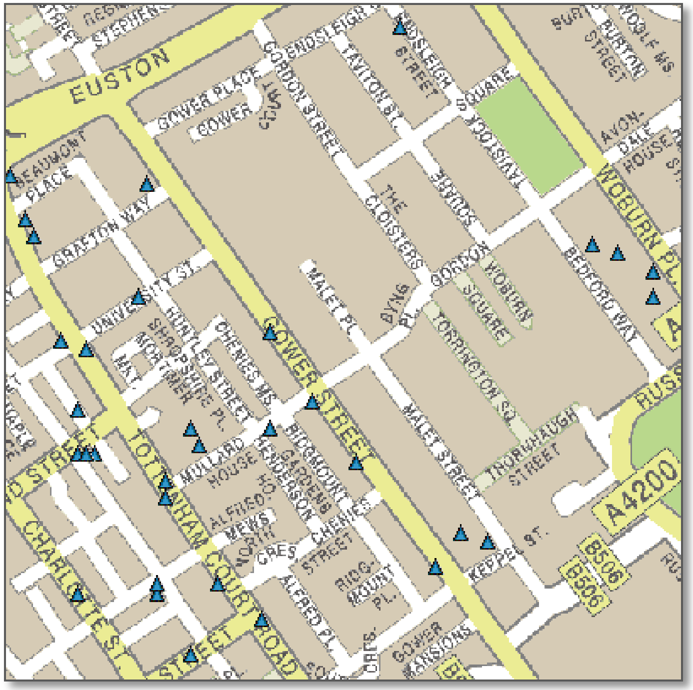


http://www.sitefinder.radio.gov.uk

Cellphone basestations



2002

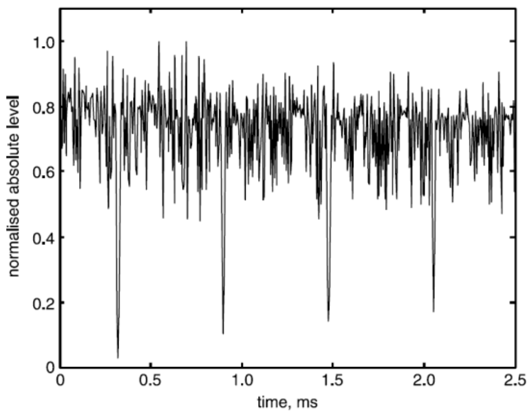


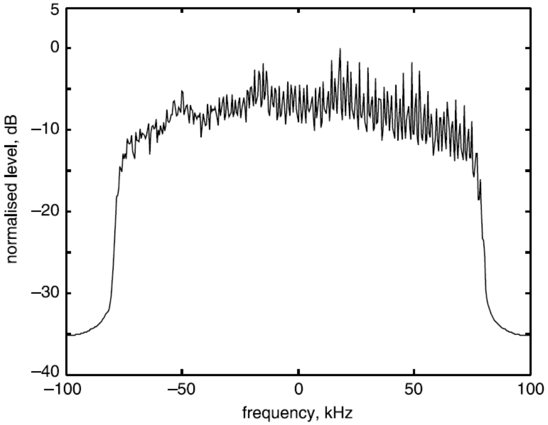
2008

http://www.sitefinder.radio.gov.uk

Cellphone basestations: GSM

- The GSM system uses bands centred on 900 MHz and 1.8 GHz, and 1.9 GHz in the USA.
- The uplink and downlink bands are each of 25 MHz bandwidth, split into 125 FDMA (Frequency Division Multiple Access) carriers spaced by 200 kHz. A given basestation will only use a small number of these channels.
- Each of these carriers is divided into 8 TDMA (Time Division Multiple Access) time slots, with each time slot of duration 577 μs.
- Each carrier is modulated with using GMSK (Gaussian Minimum-Shift Keying) modulation. A single bit corresponds to 3.692 μs, giving a modulation rate of 270.833 kbits/s.





Cellphone basestations: 3G

The third generation (3G) system uses a band in the region of 2 GHz. The UMTS (Universal Mobile Telecommunication System) is the main implementation of 3G, with the following characteristics:

- There are two forms, Frequency Division Duplex (FDD) and Time Division Duplex (TDD). FDD requires two frequency bands (for the up-link and one for the down link); TDD requires a single band. A given band (or pair of bands) is allocated to a particular operator.

- FDD and TDD bands are of 5 MHz nominal width/channel spacing. The width can be reduced (in 200 kHz steps) to 4.4 MHz if operators wish.

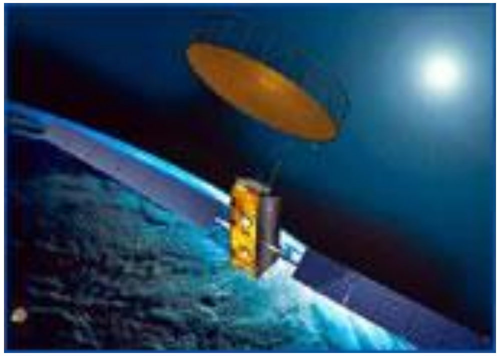
- The transmission is Wideband CDMA (WCDMA) using Walsh-Hadamard coding. The transmission rate is always 3.84 Mchips/s. The data rate may be varied, which means that the selected spreading code length is dependent on the data rate. The codes used are referred to as Orthogonal Variable Spreading Factor Codes (OSVF). Code length may vary from 4 (giving data rate of 960 kbit/s) up to 512 (giving data rate of 7.5 kbit/s). Data is also scrambled, but this does not affect the rate.

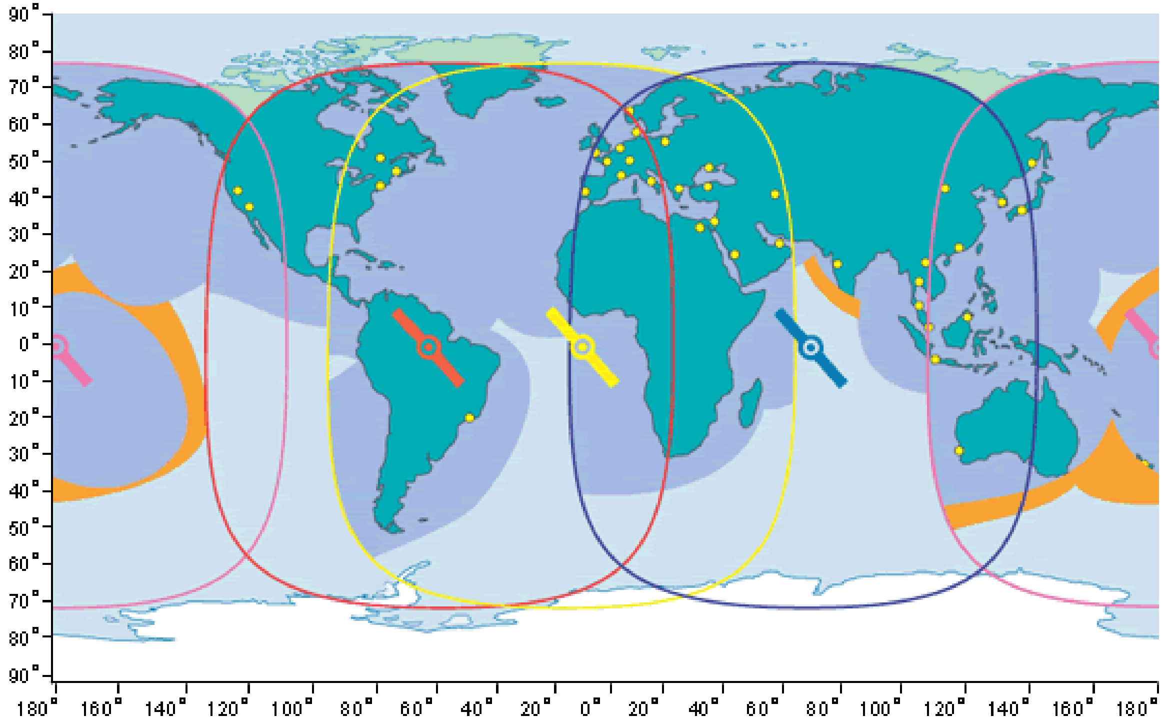
- The modulation used is QPSK. The null-to-null bandwidth is effectively 3.84 MHz, hence the 4.4 MHz minimum channel spacing. The signals are shaped with a 0.2 Root Raised Cosine Filter.

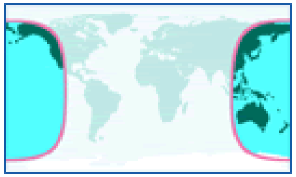
Satellite DBS TV

- Ku-band (~11 – 12 GHz)
- geostationary orbit – hence stationary, allowing long integration time
- EIRP ~ +52 dBW (HOTBIRD 5, Eutelsat 2f4, ASTRA, …)
- several such satellites, but beams shaped to give coverage over land

INMARSAT-3

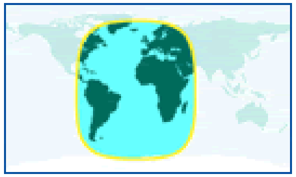






Pacific Ocean Region

Atlantic Ocean Region-West



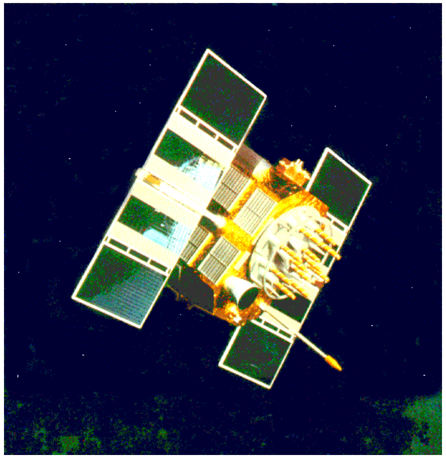
Atlantic Ocean Region-East

Indian Ocean Region

http://www.inmarsat.com

GPS / GLONASS / GALILEO

- each consists of a network of 24 satellites; orbit height ~20,000 km
- both systems L-band (1200 – 1600 MHz)
- GPS is CDMA, GLONASS is FDMA
- bandwidths between 1 MHz and 10 MHz
- $\Phi = -134$ dBW/m^2 on ground
- timing and synchronisation not a problem !
- claimed 60 – 70 dB processing gain (1 Hz b/w)



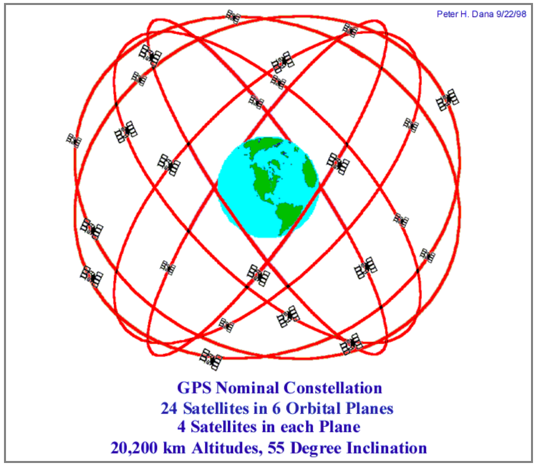


Table 1: Major orbit parameters of GPS, GLONASS and Galileo systems

Parameter	GPS system	GLONASS system	Galileo system
Number of active satellites	24	24	30
Number of orbital planes	6	3	3
Orbital inclination	55°	64.8°	56°
Orbit altitude	20 183 km	19 130 km	23 616 km
Period of revolution	11 h 58 min 00 s	11 h 15 min 40 s	14 h 4 min
Absolute velocity of satellites	3870 m/s	3950 m/s	3720 m/s

He, X., Cherniakov, M. and Zeng, T., 'Signal detectability in SS-BSAR with GNSS non-cooperative transmitters'; Special Issue of *IEE Proc. Radar, Sonar and Navigation* on Passive Radar Systems, Vol.152, No.3, pp124–132, June 2005.

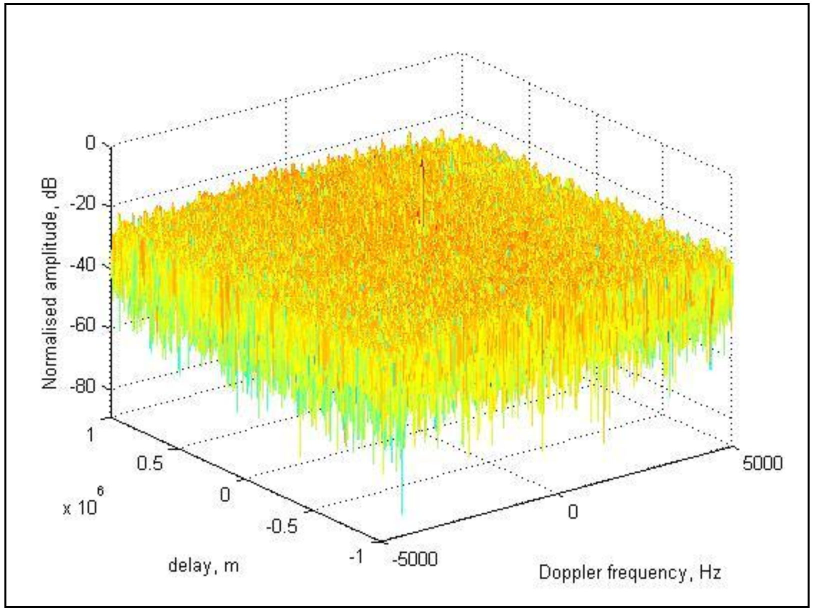
HF broadcast

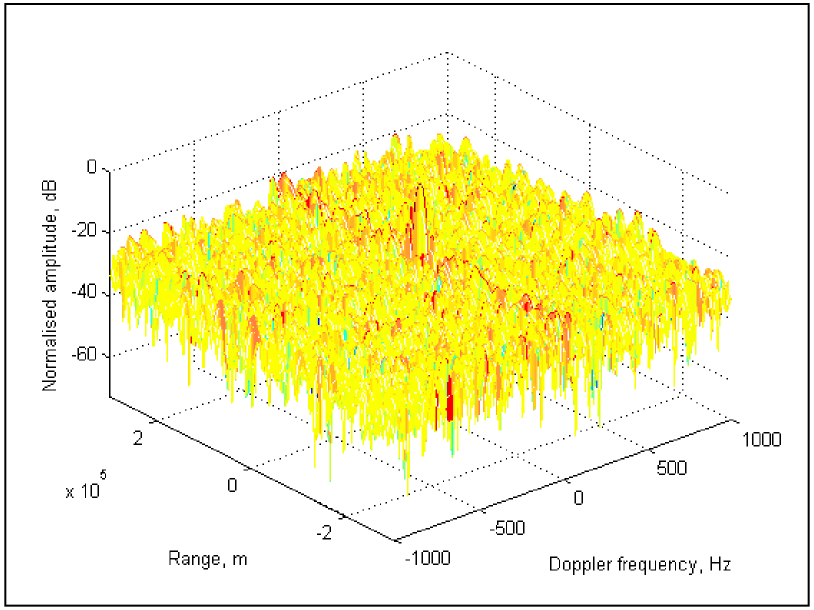
- HF (10 – 30 MHz): eg BBC World Service, Voice of America, ….
- P_t as much as 500 kW, G_t 20 dBi (Sterba Curtain, Rhombic)
- EIRP ~50 MW (max); DSB AM b/w ~9 kHz (c/2B = 17 km)

Φ at 1,000 km: –67 to –53 dBW/m^2
(daytime, 17.8 MHz; nighttime, 9.8 MHz)

- poor resolution, both in azimuth and range
- may allow forward scatter geometry; broad angular scattering, but target RCS not as high as at higher frequencies
- subject to propagation distortion – but maybe not so bad with remote tx and target relatively close to rx (Stuart Anderson)
- Digital Radio Mondiale (DRM)

Digital Radio Mondiale (DRM)

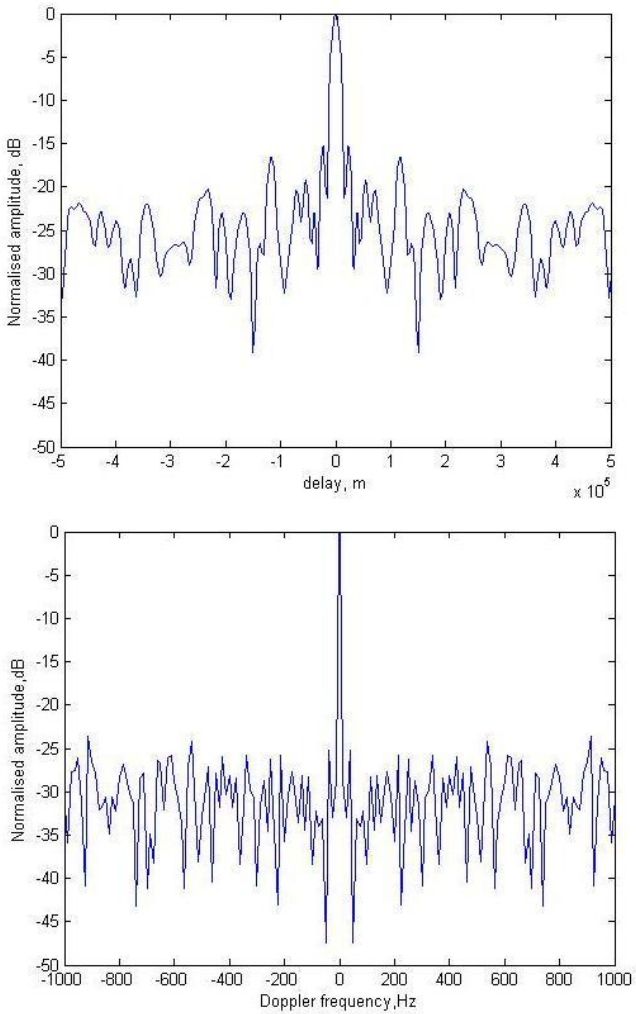




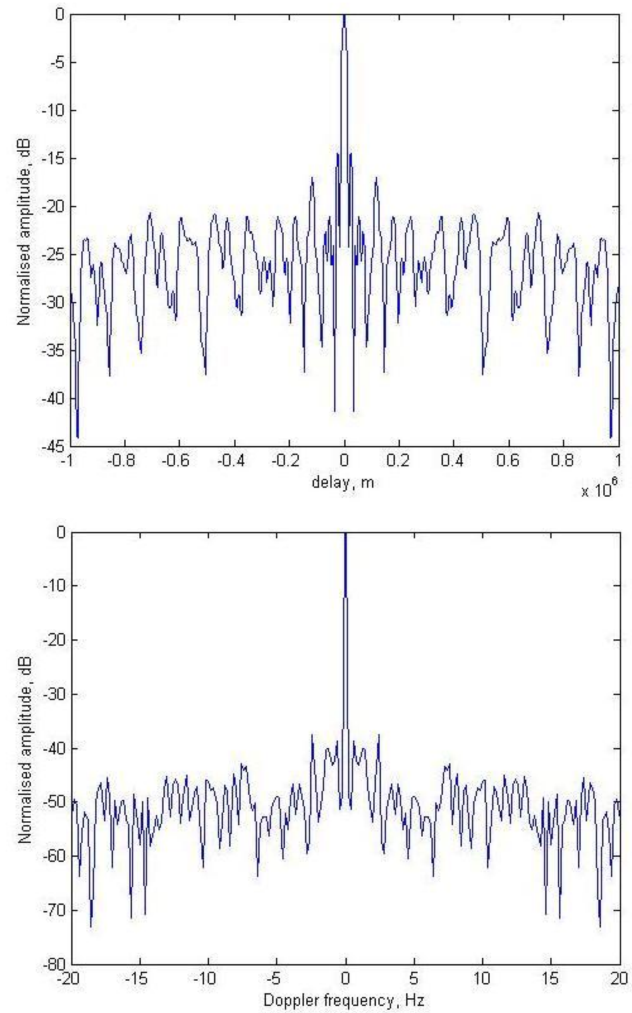
Normalised ambiguity function for DRM signal with 80ms integration time

Thomas, J.M., Griffiths, H.D. and Baker, C.J., 'Ambiguity function analysis of Digital Radio Mondiale signals for HF passive bistatic radar applications', *Electronics Letters*, Vol.42, No 25, pp1482–1483, 7 December 2006.

Digital Radio Mondiale (DRM)



Ambiguity function range (above) and Doppler (below) cuts



Ambiguity function Doppler cut for an integration time of 5s

HF OTHR radar

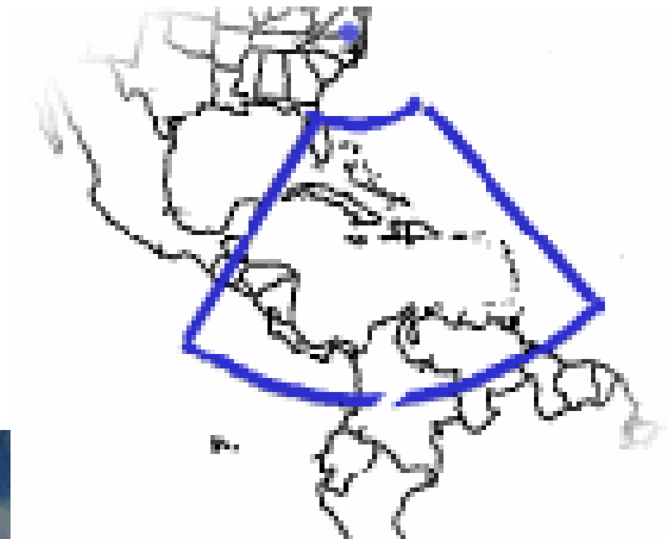
- ROTHR: P_t 200 kW (average), G_t 20 dBi, tx b/w 8º
  frequency 5 – 28 MHz, vertical polarisation
  FM/CW waveform, 4 – 100 kHz bandwidth

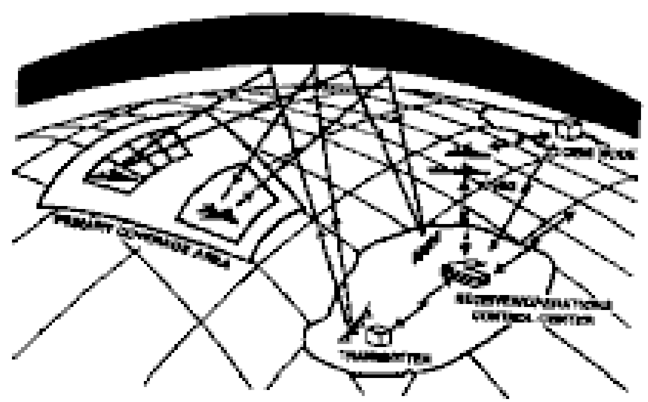
- JINDALEE P_t 560 kW average, G_t 20 dBi, tx b/w 16º
  frequency 6 – 28 MHz, vertical polarisation
  FM/CW waveform

- subject to propagation distortion, as with HF broadcast – but maybe not so bad with remote tx and target relatively close to rx

- Moving target Doppler will be low, due to low frequency and small angles

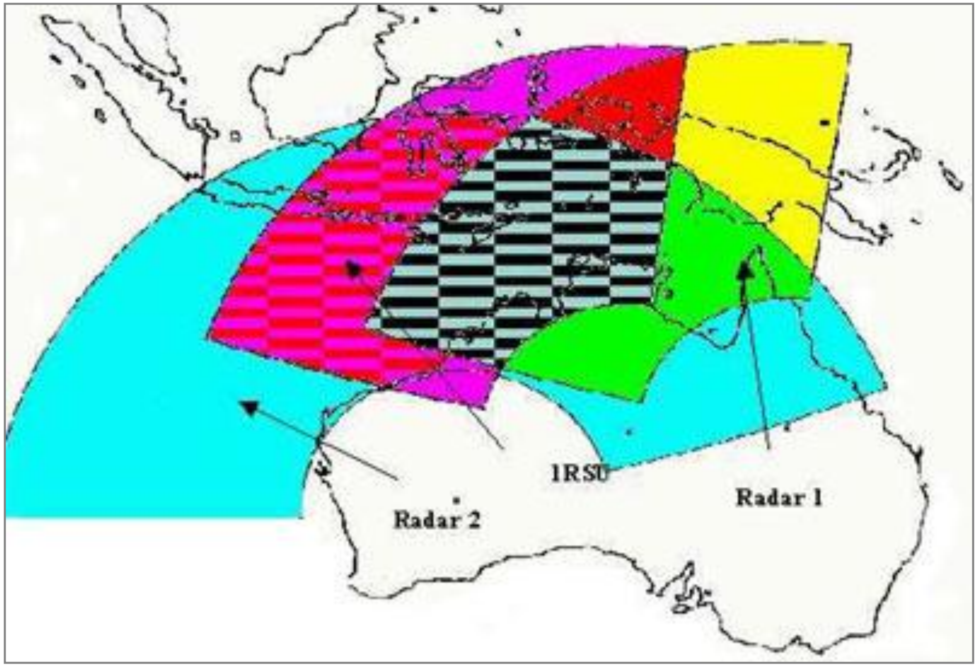
ROTHR – Relocatable Over The Horizon Radar AN/TPS-71



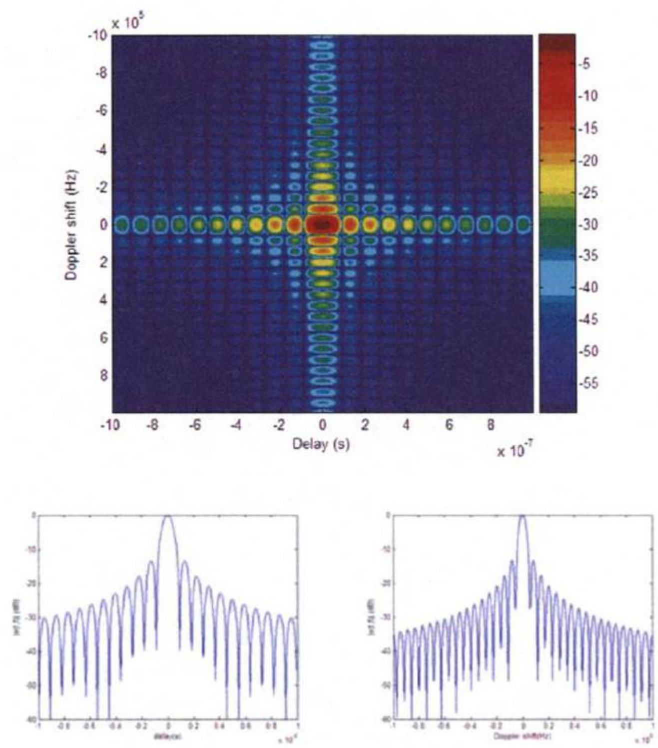


The ROTHR concept.

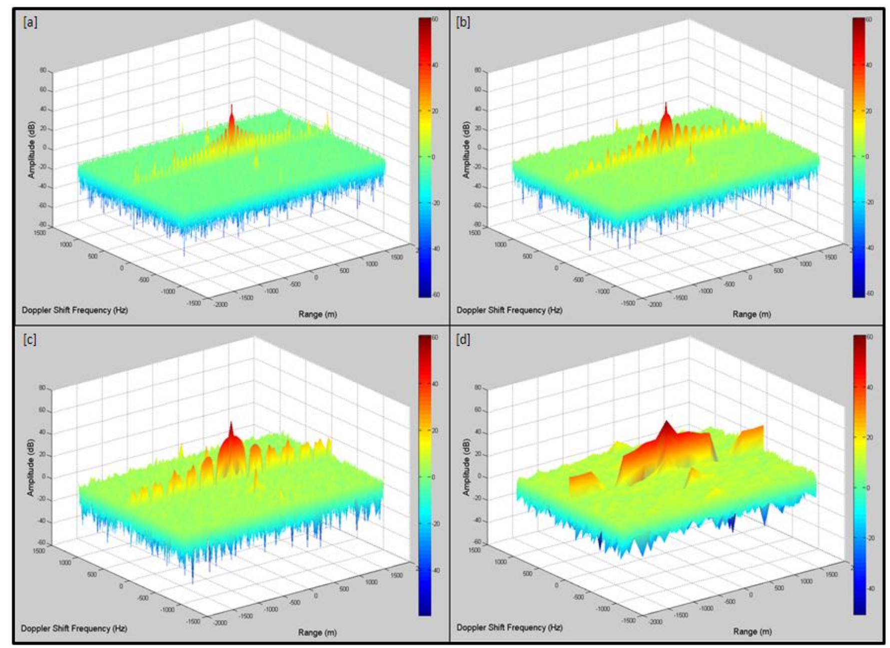
Jindalee (JORN)



WiFi and WiMAX



WiFi

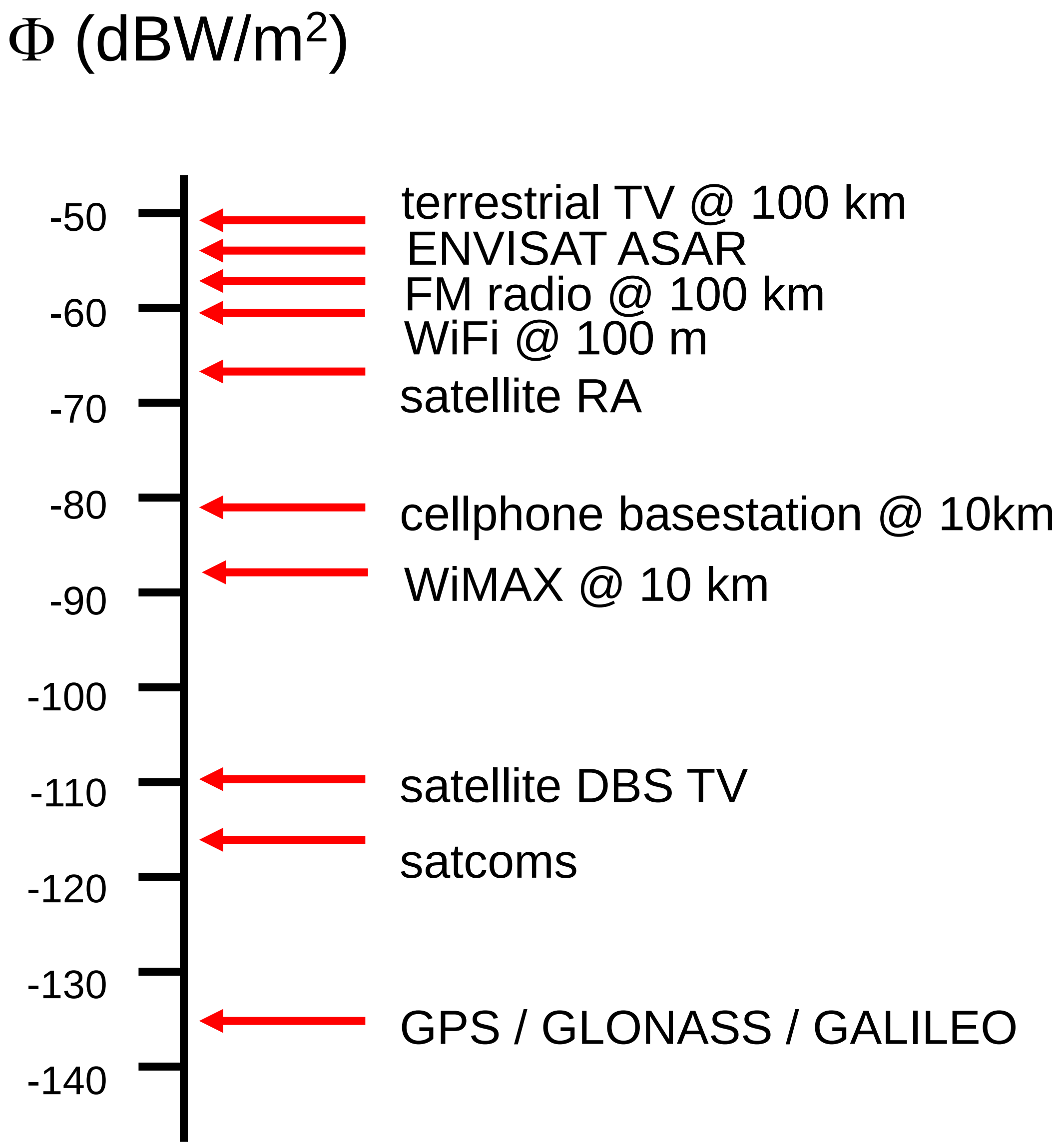


WiMAX

Guo, Hui, S. Coetzee, D. Mason, K. Woodbridge and C.J. Baker, ‘Passive radar detection using wireless networks’, Proc. IET International Radar Conference *RADAR 2007*, Edinburgh, pp1–4, September 2007.

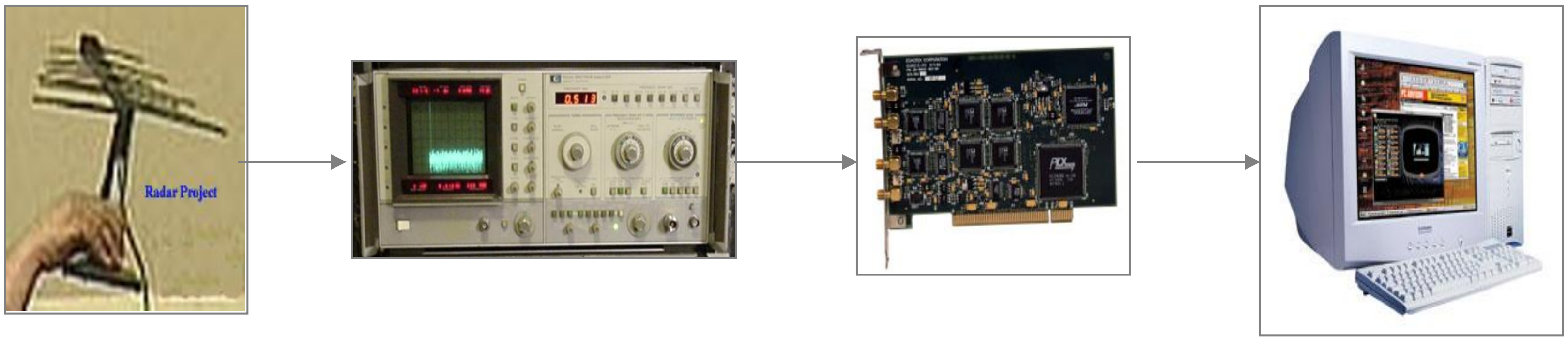
K. Chetty, K. Woodbridge, Guo, Hui and G.E. Smith, ‘Passive bistatic WiMAX radar for marine surveillance’, Proc. IEEE International Radar Conference *RADAR 2010*, Washington DC, 10–14 May 2010.

Comparison of power densities



calculated on the basis of a single channel, free space propagation, whole signal, no processing gain

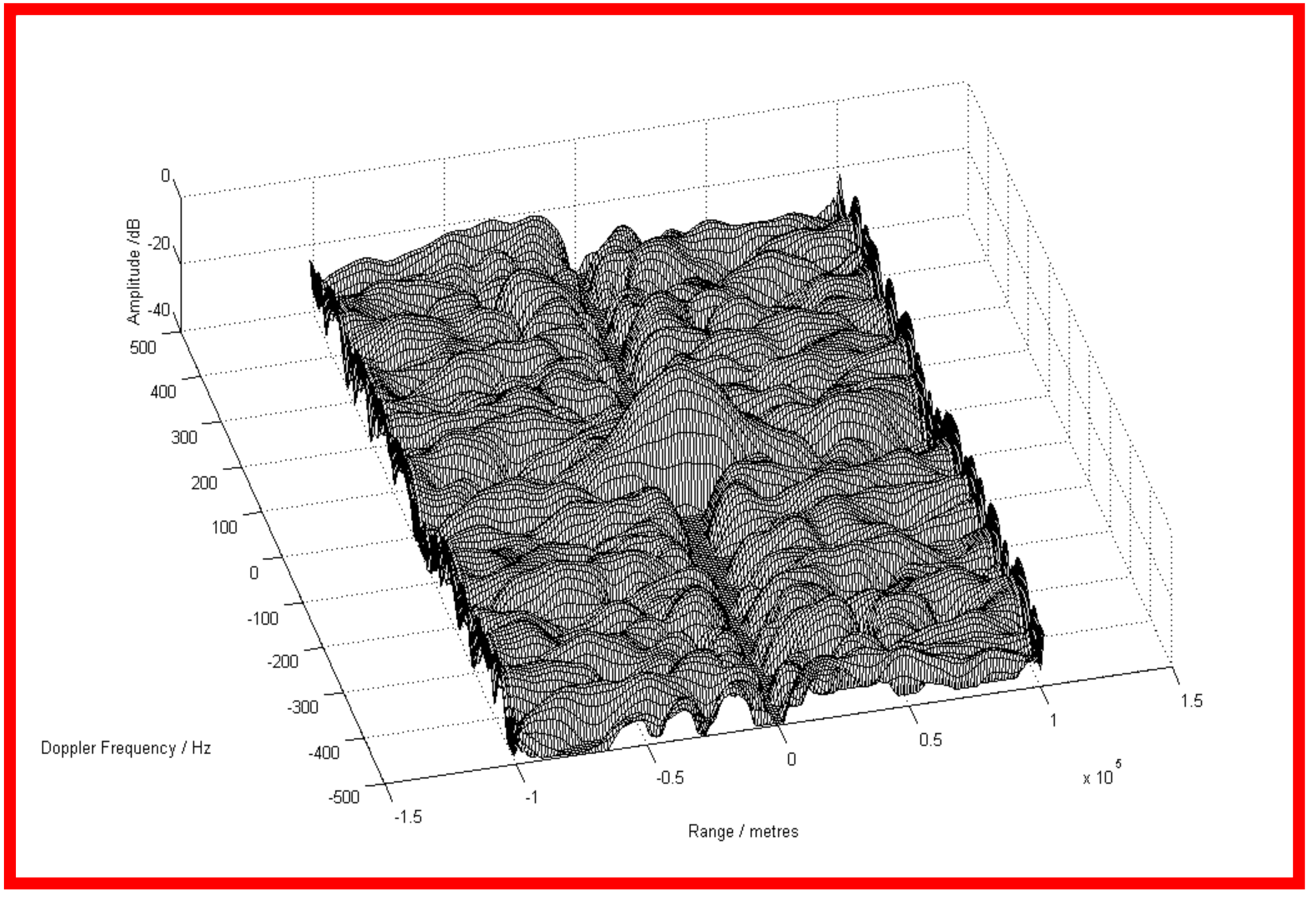
Experimental system



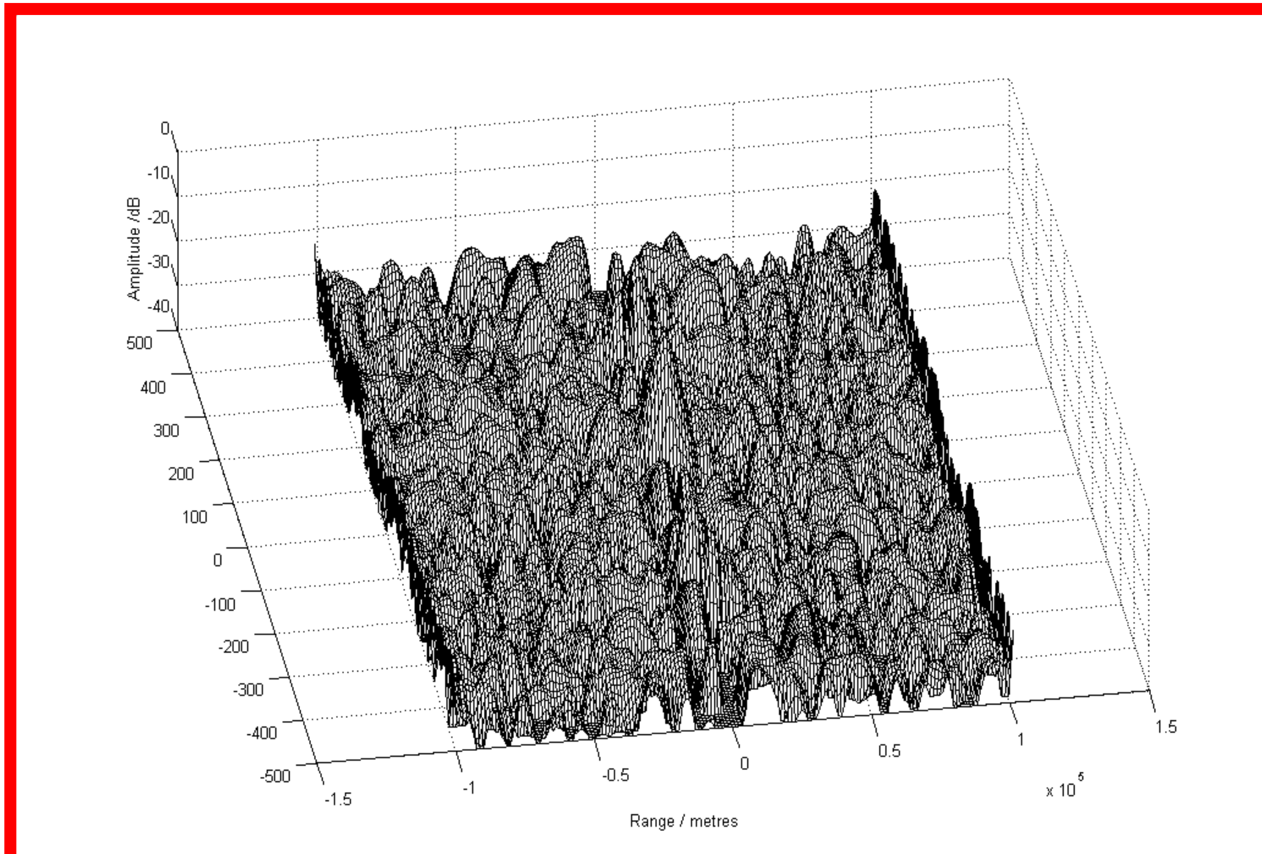
- HP 8565A spectrum analyser
- flexible and highly linear, but poor noise figure
- Echotek ECDR 214 PCI digitizer card

Griffiths, H.D., Baker, C.J., Ghaleb, H., Ramakrishnan, R. and Willman, E., ‘Measurement and analysis of ambiguity functions of off-air signals for passive coherent location’, *Electronics Letters*, Vol.39, No.13, pp1005–1007, 26 June 2003.

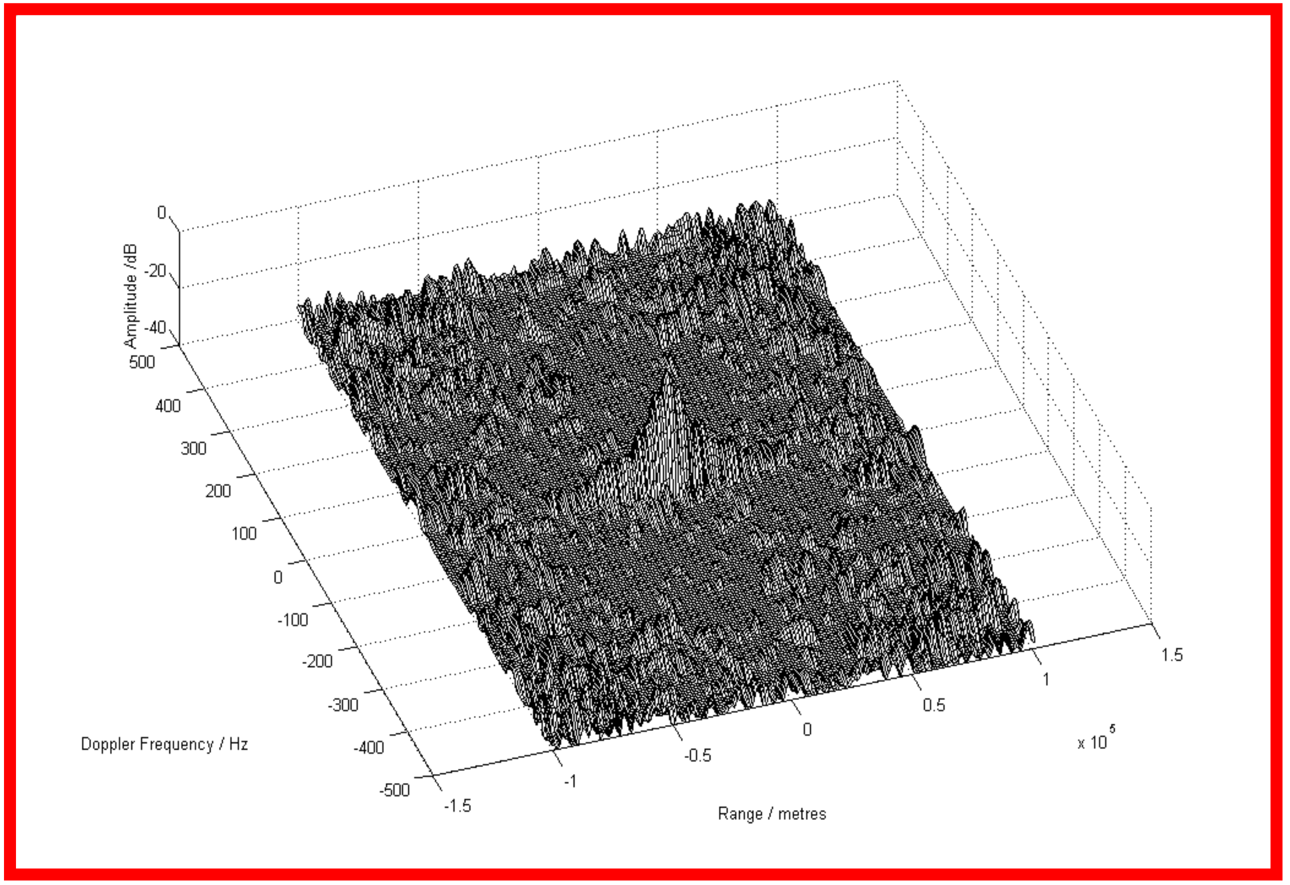
BBC Radio 4 (news) 93.5 MHz



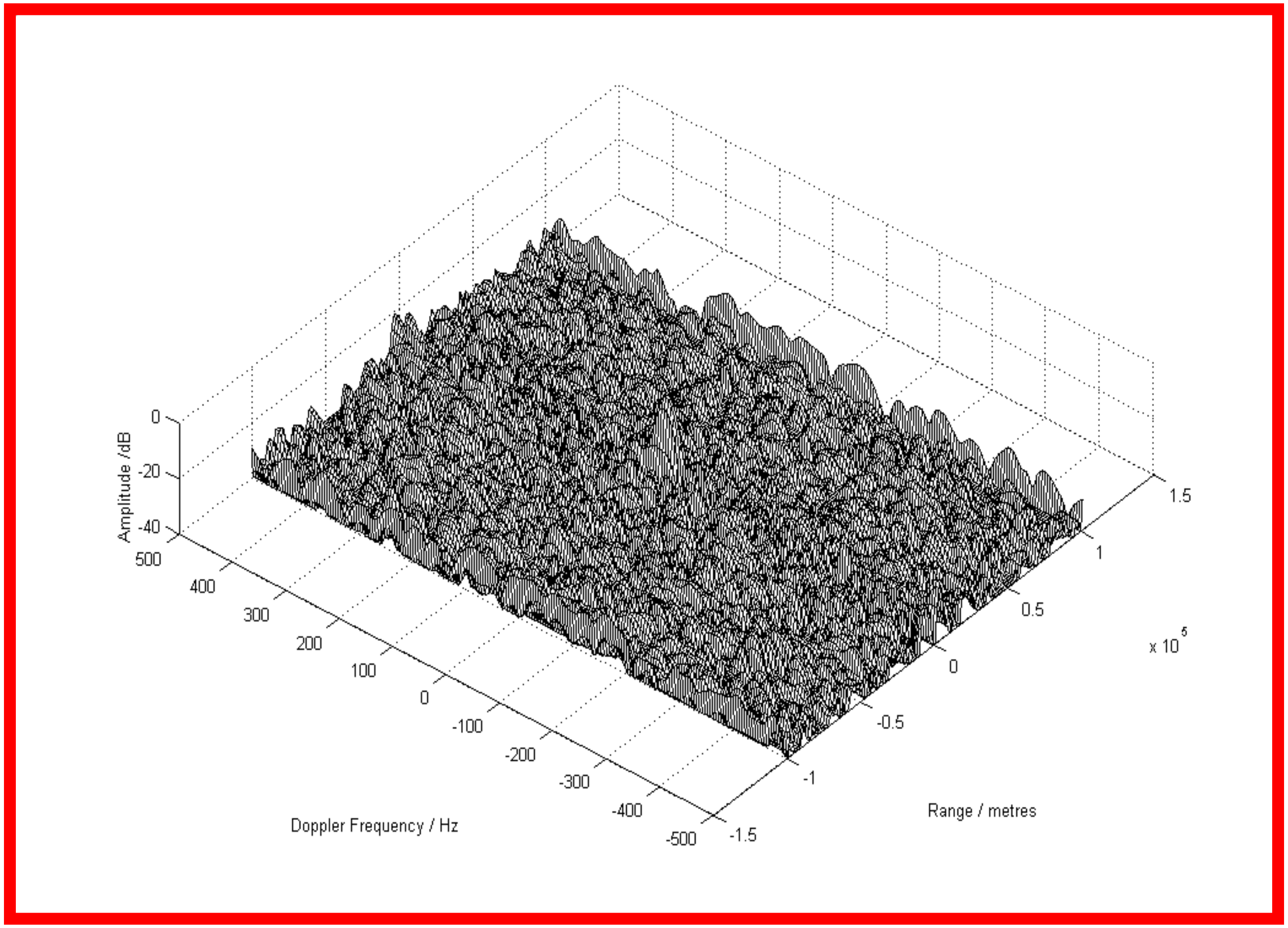
Jazz FM (fast tempo) 102.2 MHz



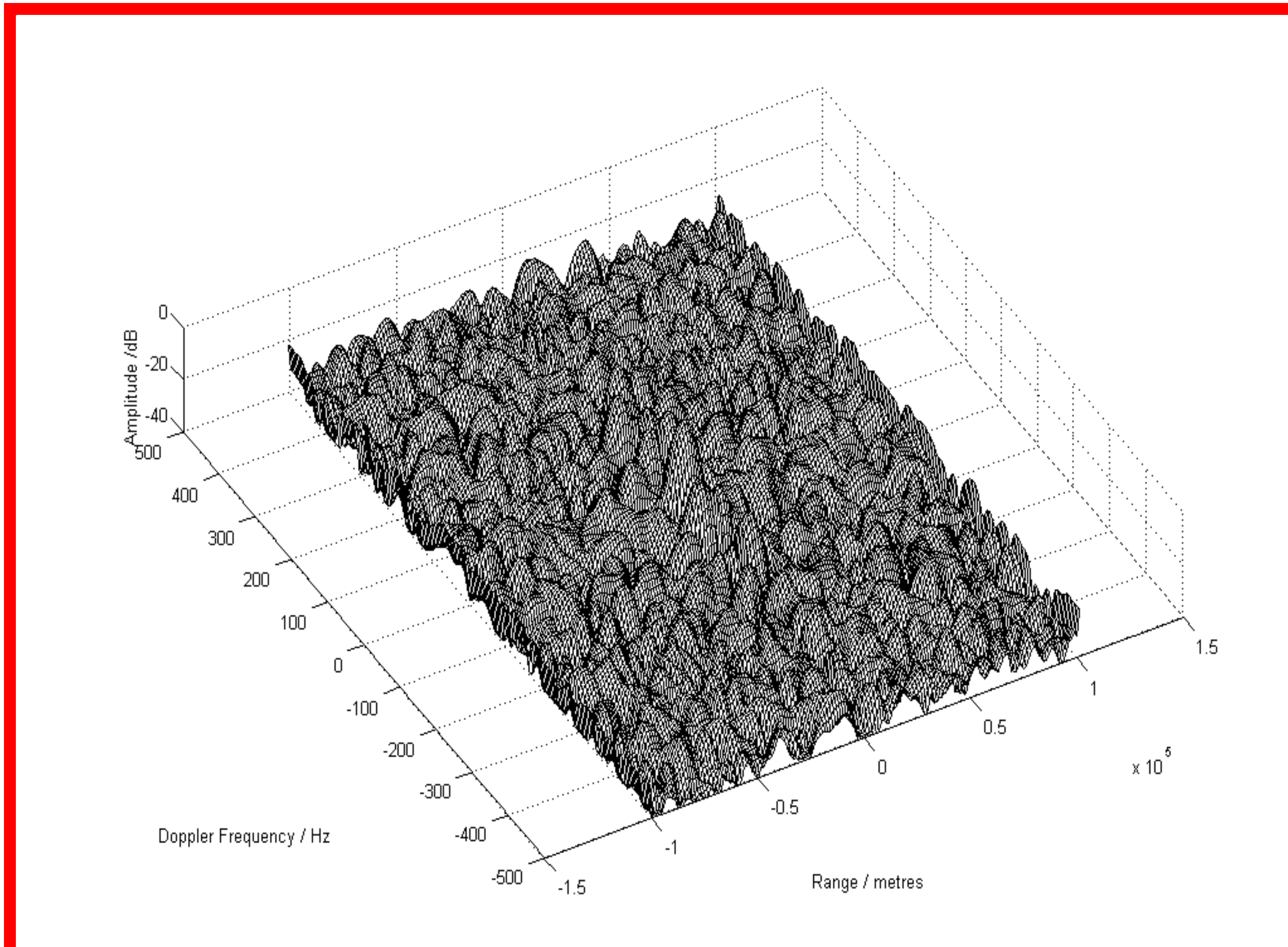
Digital Audio Broadcast 222.4 MHz



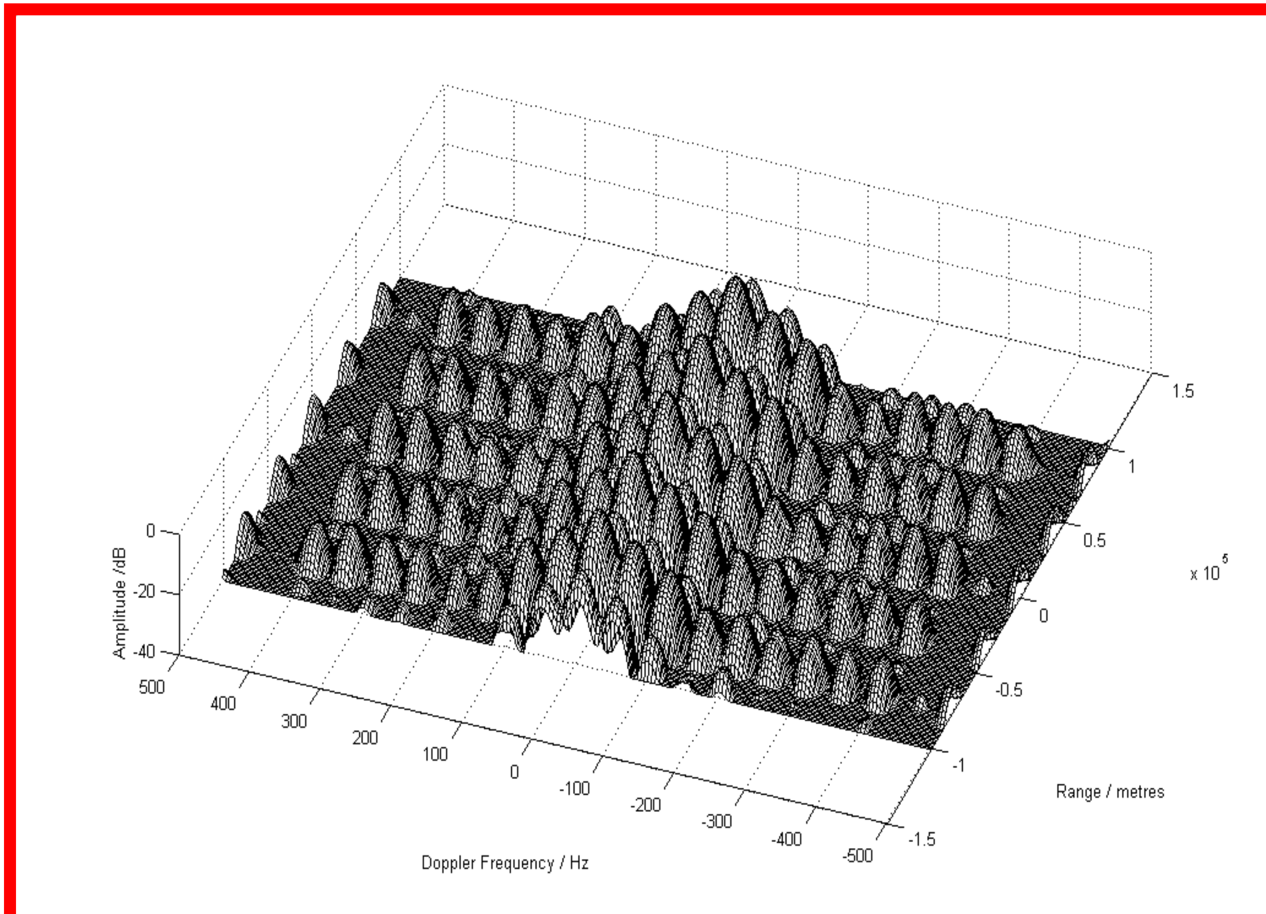
Reggae – Choice FM 107.1 MHz



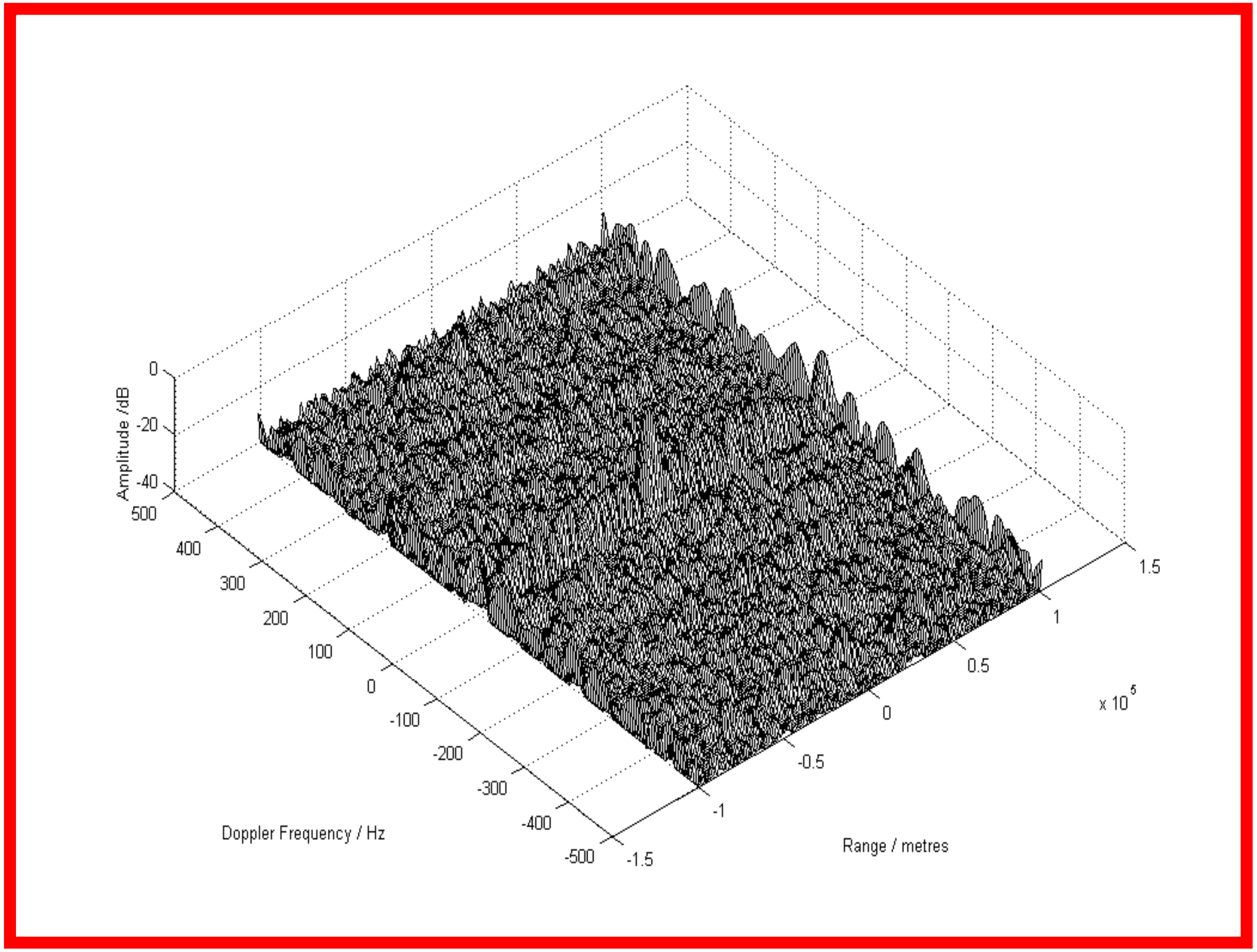
Jazz FM (medium tempo) 102.2 MHz



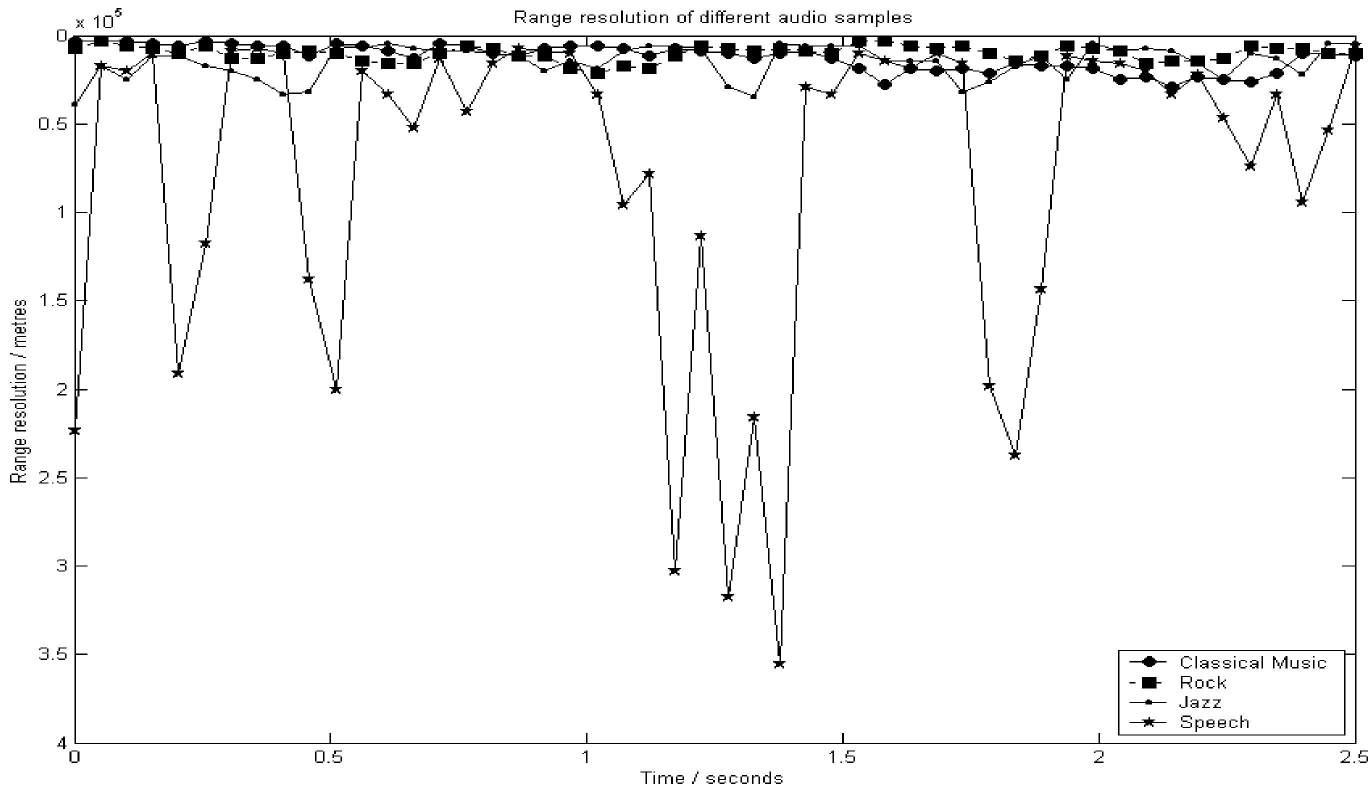
Analogue TV chrominance subcarrier 491.55 MHz (ITV1)



GSM 900 944.6 MHz

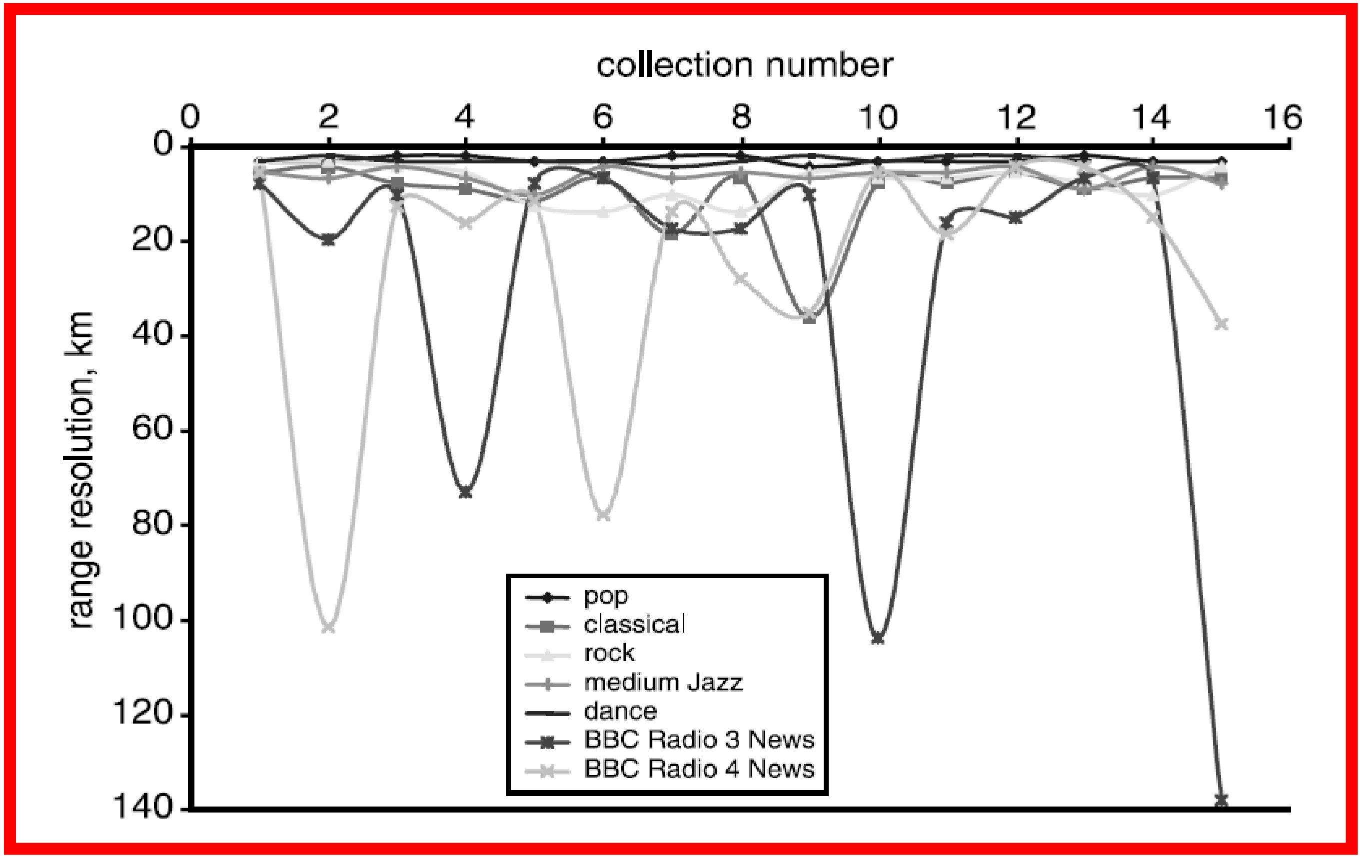


Dependence on instantaneous modulation



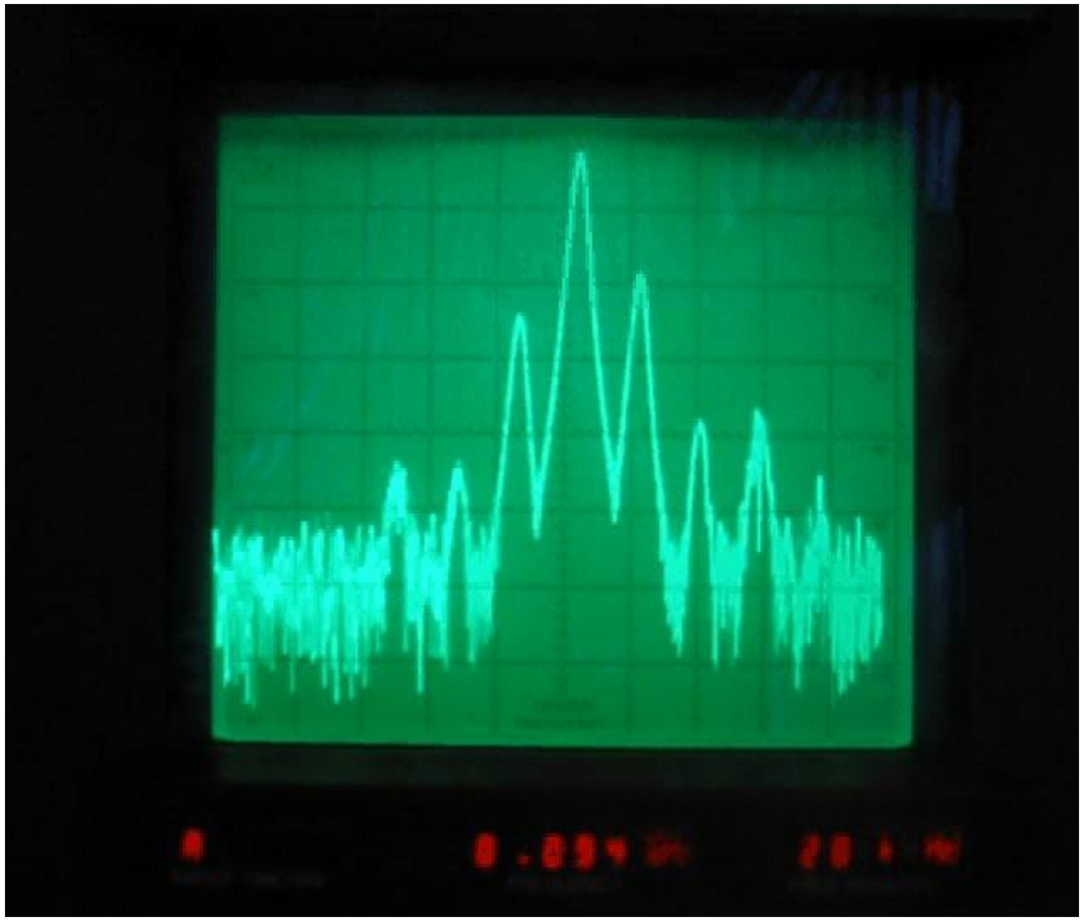
Variation in range resolution as a function of time for four types of VHF FM radio modulation.

Dependence on instantaneous modulation



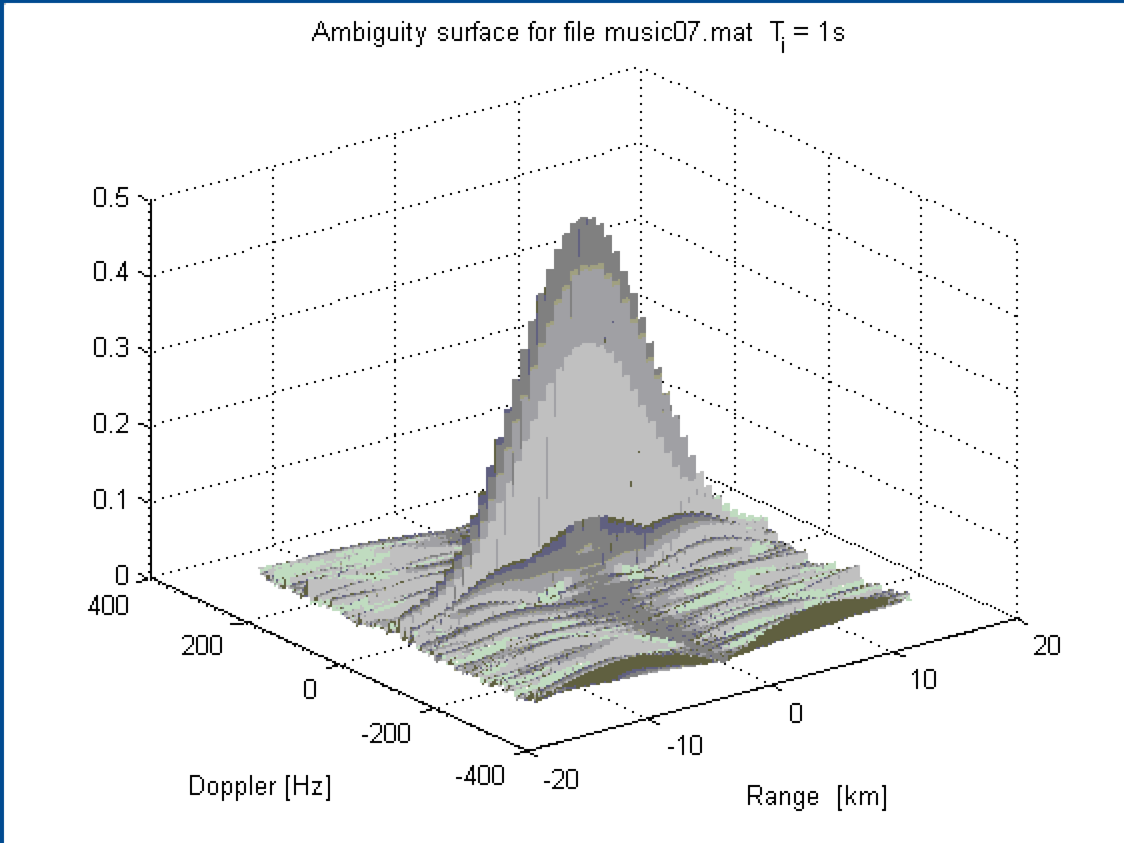
Variation in range resolution as a function of time for seven types of VHF FM radio modulation.

Dependence on instantaneous modulation

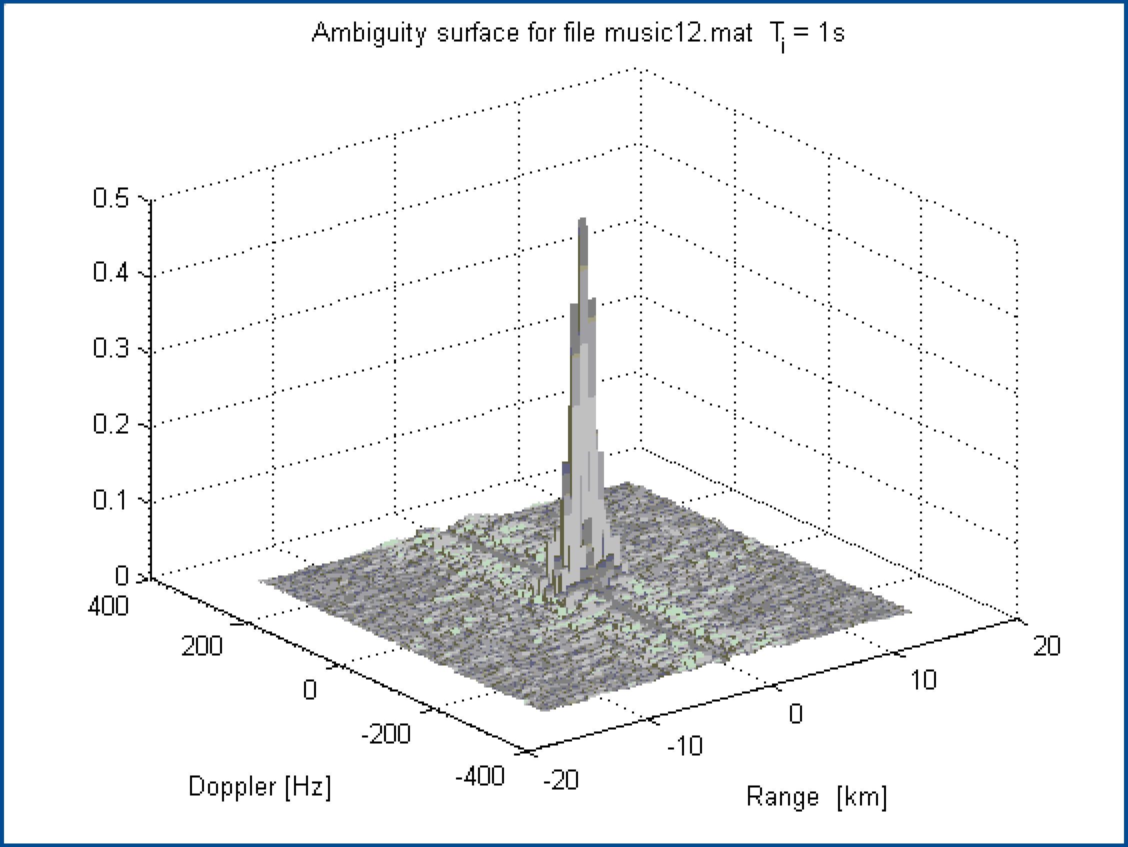


BBC Radio 4 93.5 MHz (speech)
Vertical scale: 10 dB/div
Horizontal scale: 20 kHz/div

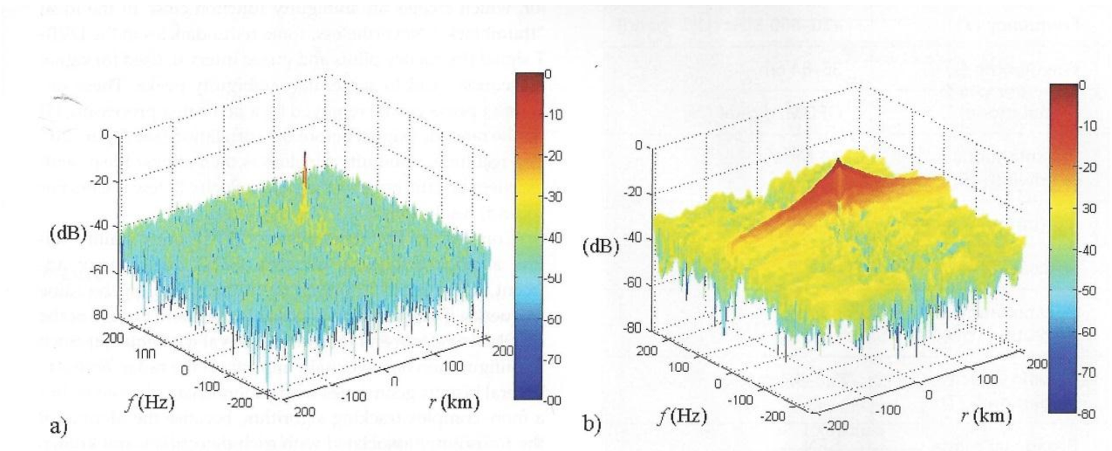
Ambiguity Surface (FM - Techno)



Ambiguity Surface (FM - Punk)



FM radio ambiguity functions



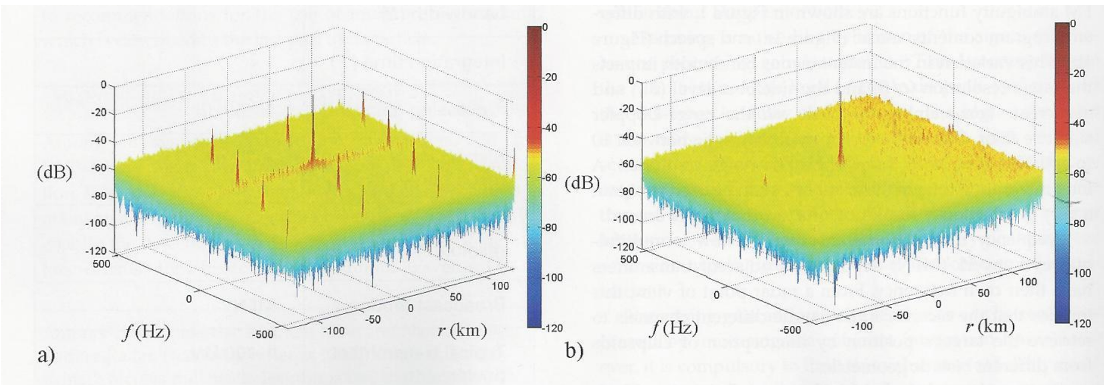
music

speech

FM Signal—Radar Characteristics	
Parameters	**Value**
Frequency (f)	88–108 MHz (VHF band)
Wavelength (λ)	2.7–3.4 m
Signal model	FM, analog CW
Instantaneous bandwidth (B)	10–100 kHz
Integration time (T)	1 s
Processing gain (BT)	40–50 dB
Bistatic range resolution (c/B)	3–30 km
Bistatic velocity resolution (λ/T)	2.7–3.4 m/s
Broadcast mode	MFN
Typical transmitted power	1–100 kW
Altitude coverage	Low, medium, high

Klein, M. and Millet, N., ‘Multireceiver passive radar tracking’, *IEEE AES Magazine*, Vol.27, No.10, pp26–36, 26 October 2012.

DVB-T ambiguity functions



before

after dedicated reference signal processing

DVB-T Signal—Radar Characteristics

Parameters	Value
Frequency (f)	470–860 MHz (UHF band)
Wavelength (λ)	35–64 cm
Signal model	OFDM, digital CW
Instantaneous bandwidth (B)	7.6 MHz
Integration time (T)	0.1 s
Processing gain (BT)	59 dB
Bistatic range resolution (c/B)	40 m
Bistatic velocity resolution (λ/T)	3.5–6.4 m/s
Broadcast mode	SFN
Typical transmitted power	1–100 kW
Altitude coverage	Low, very low

Klein, M. and Millet, N., ‘Multireceiver passive radar tracking’, *IEEE AES Magazine*, Vol.27, No.10, pp26–36, 26 October 2012.

Summary

Transmission	Frequency	Modulation, bandwidth	$P_t G_t$	Power density (note 1) $\Phi = \frac{P_t G_t}{4\pi R_T^2}$
HF broadcast	10 – 30 MHz	DSB AM, 9 kHz	50 MW	–67 to –53 dBW/m² at R_T = 1,000 km
VHF FM	88 – 108 MHz	FM, 50 kHz	250 kW	–57 dBW/m² at R_T = 100 km
Analogue TV	~ 550 MHz	PAL, SECAM, NTSC 5.5 MHz	1 MW	–51 dBW/m² at R_T = 100 km
DAB	~ 220 MHz	digital, OFDM 220 kHz	10 kW	–71 dBW/m² at R_T = 100 km
Digital TV	~ 750 MHz	digital, 6 MHz	8 kW	–71 dBW/m² at R_T = 100 km
Cellphone basestation (GSM)	900 MHz, 1.8 GHz	GMSK, FDMA/TDMA/FDD 200 kHz	10 W	–81 dBW/m² at R_T = 10 km
Cellphone basestation (3G)	2 GHz	CDMA, 5 MHz	10 W	–81 dBW/m² at R_T = 10 km
WiFi 802.11	2.4 GHz	DSSS/OFDM, 5 MHz	100 mW	–41 dBW/m² (note 2) at R_T = 10 m
WiMAX 802.16	2.4 GHz	QAM, 20 MHz	20 W	–88 dBW/m² at R_T = 10 km
GNSS	L-band	CDMA, FDMA 1 – 10 MHz	200 W	–134 dBW/m² at Earth's surface
DBS TV	Ku-band 11 – 12 GHz	analogue and digital	55 dBW	–107 dBW/m² at Earth's surface
Satellite SAR (note 3)	5.3 GHz	chirp pulse, 15 MHz	68 MW	–55 dBW/m² at Earth's surface

Notes: [1] assuming free space line-of-sight propagation
[2] would be subject to additional attenuation due to propagation through walls
[3] parameters from ASAR instrument carried by ESA's ENVISAT satellite

Summary

- for analogue modulation formats, ambiguity performance depends strongly on instantaneous modulation
- periodic modulation features result in ambiguities
- for VHF FM radio the ambiguity performance varies significantly, and some types of music are better than others
- with speech, the ambiguity performance is poor during pauses between words
- for digital modulation formats, ambiguity performance is much more constant, since signals are more noise-like