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COLLEGE ON THEORETICAL AND EXPERIMENTAL RADIOPROPAGATION SCIENCE

6 - 24 February 1989

THE OLYMPUS EXPERIMENT AND A NEW SATELLITE BEACON RECEIVER

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College on theoretical and experimental radiopropagation physics

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Laboratory session

The Olympus experiment and a new satellite beacon receiver

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Trieste 22/2/1989

Satellite characteristics of Olympus

- Experimental 3-axis stabilized spacecraft designed to meet the payload requirements of future communications satellites.

- The platform allows to accomodate a payload of

  425 Kg 5.5 KW

- Satellite mission lifetime 7 years

- Olympus will carry three payloads:
  - 12/14 specialized service (Advanced communications with small E/S)
  - Direct broadcasting payload
  - 20/30 communication payload
  - 12/20/30 propagation package (point-to-point and multipoint teleconferences)

Propagation beacon payload

— The payload consists of three CW beacons transmitted at:

B_0 12501.866 MHz B_1 19770.393 MHz B_2 29655.589 MHz

— All the beacons are coherently derived from a single source

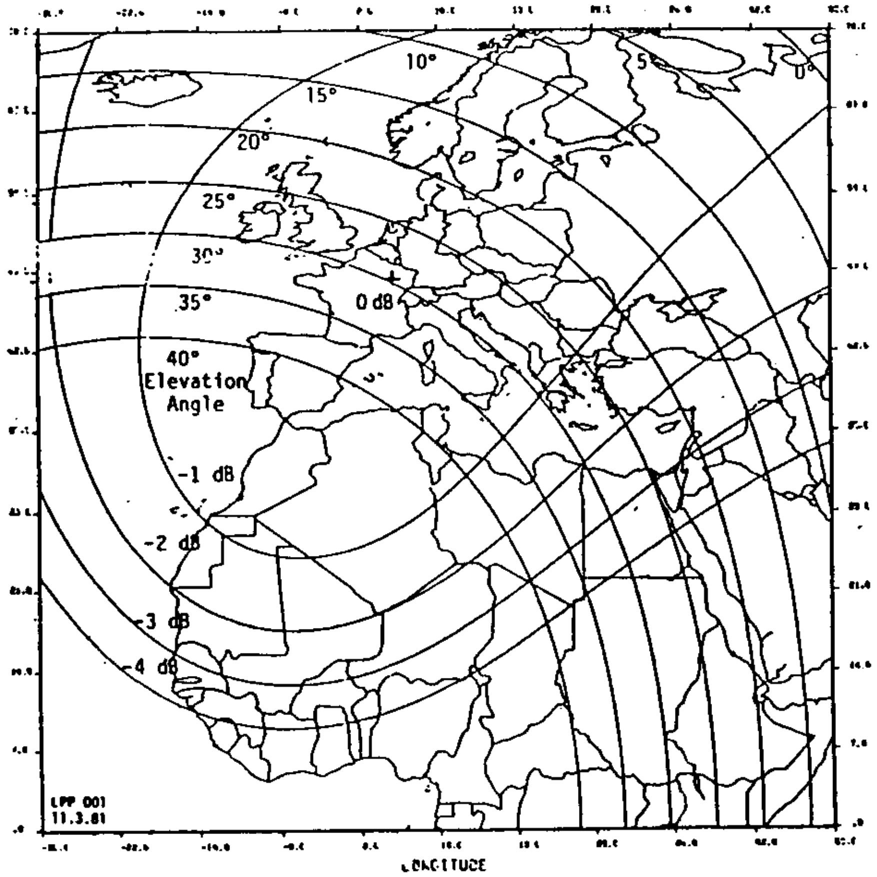
— Frequency stability

Period	Signal B_0	Signal B_1	Signal B_2
Over any 24 hours	± 1.2 KHz	± 2 KHz	± 3 KHz
Over any year	± 36 KHz	± 60 KHz	± 90 KHz
Over 7 years	± 120 KHz	± 200 KHz	± 300 KHz

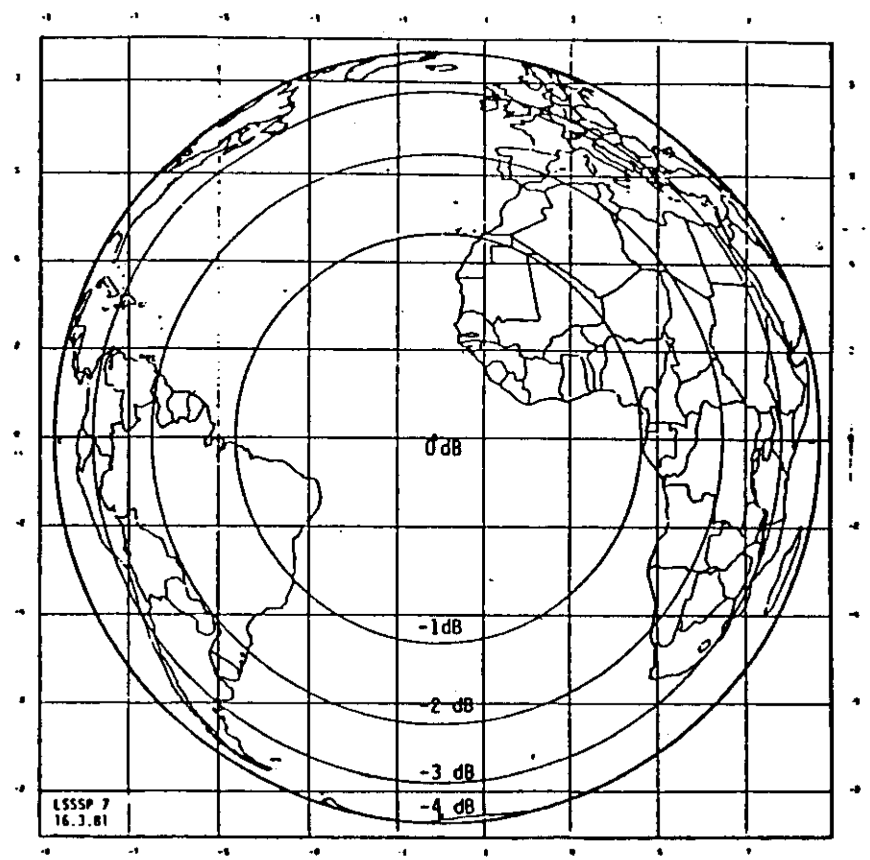
— EIRP B_0 10 dBW B_1 24 dBW B_2 24 dBW

— EIRP stability

Time interval	EIRP variation B_0, B_1, B_2
Over any 1 sec	± 0.05 dB
Over any 24 hrs	± 0.5 dB
Over any year	± 1.0 dB
Over 7 year	± 2.0 dB

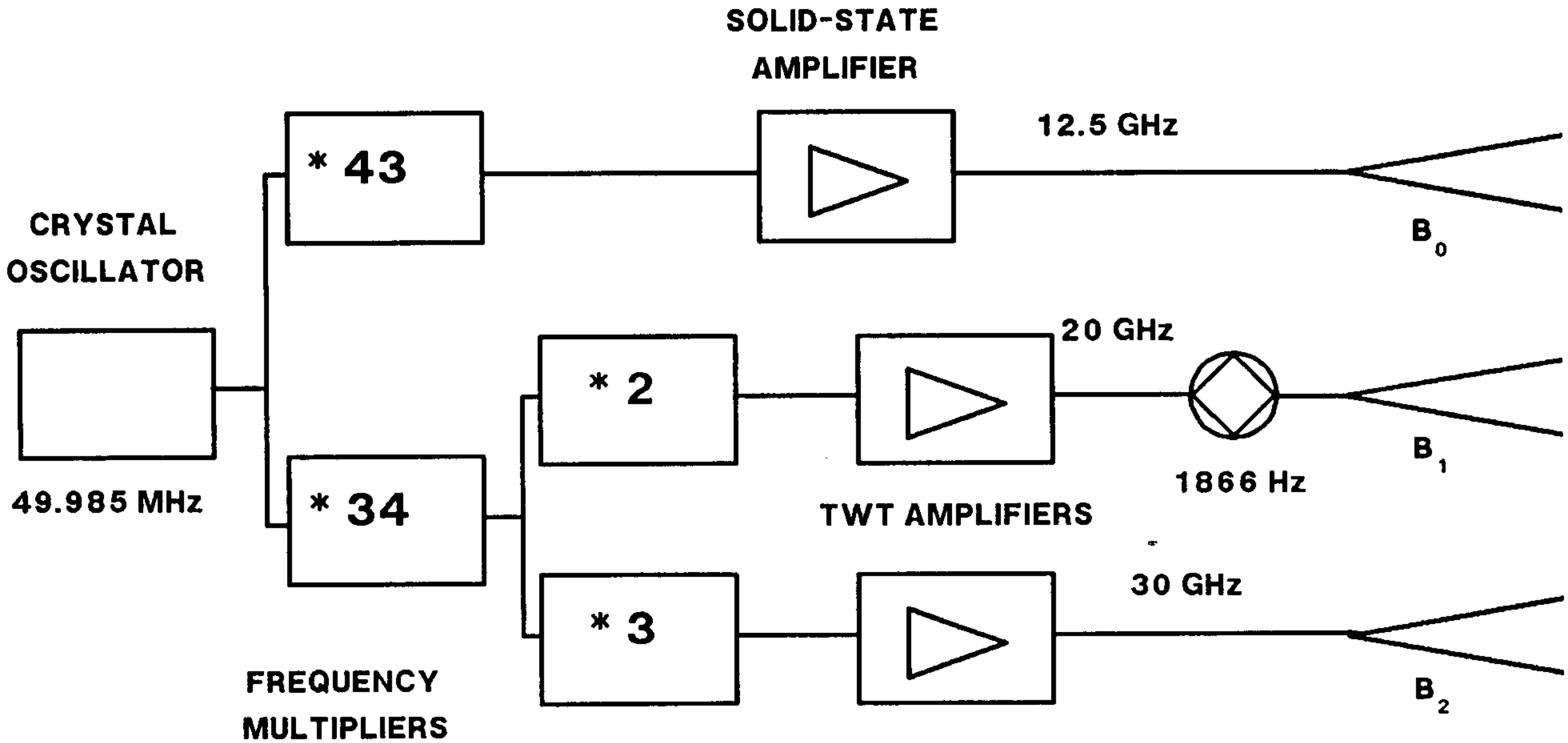


Coverage of OLYMPUS 20 GHz and 30 GHz Beacons
(showing power contours relative to peak at
beam centre and elevations)



Coverage of OLYMPUS 12.5 GHz Beacon
(with power contours relative to peak
at sub-satellite point)

Block diagram of the OLYMPUS Beacon Payload



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Y3.DRW

Polarization characteristics

— The polarization of all the beacons will be linear

— The polarization of B_1 will be either X or Y continuously, or switching between X and Y at a rate of 1866 Hz

(Full switching cycle frequency 933 Hz)

— The switching frequency will be better than +/- 2.5 parts in 10^5

— Phase variation between the two polarizations less than 2 deg/24 h

Signal	Polarisation	Orientation/Accuracy
B_1	Y	(90 ±2) degrees with respect to Earth equatorial plane.
	X	90 degrees with respect to B_1 - Y.
B_2, B_0	Y	(0 ± 0.5) degrees with respect to B_1 - Y.

Polarization orientation

SATELLITE BEACON RECEIVERS

DETECTION TECHNIQUES

- Analogue detection: it measures the amplitude of the unmodulated beacons

- non-coherent receiver: sensitivity penalty

- coherent receiver: the reference carrier at the input of PLL phase sensitivity detector is at 90 deg compared to the signal input. The signal can be multiplied by a 90 deg shifted carrier to give its amplitude.

In case of switched polarization beacon:

necessary to separate the signal received in the time domain (switching synchronous to satellite)

SATELLITE BEACON RECEIVERS

THE SAMPLING PROCESS

- Post detection filtering to the final measurement bandwidth followed by A/D conversion at 15/16 bit

- Relatively wide post-detection filtering, followed by A/D conversion at a high sampling rate with 10/12 bit A/D

  Disadvantage:

  - As the output of the detector can be positive or negative the A/D converter has to accomodate the full range.

  - The resolution in amplitude and phase after the converters depends on the signal amplitude and phase.

- Conversion to phase and logarithmic amplitude by analogue hardware followed by a 10 bit A/D conversion.

  Disadvantage:

  - The accuracy is determined by the inherent drift and non-linearity

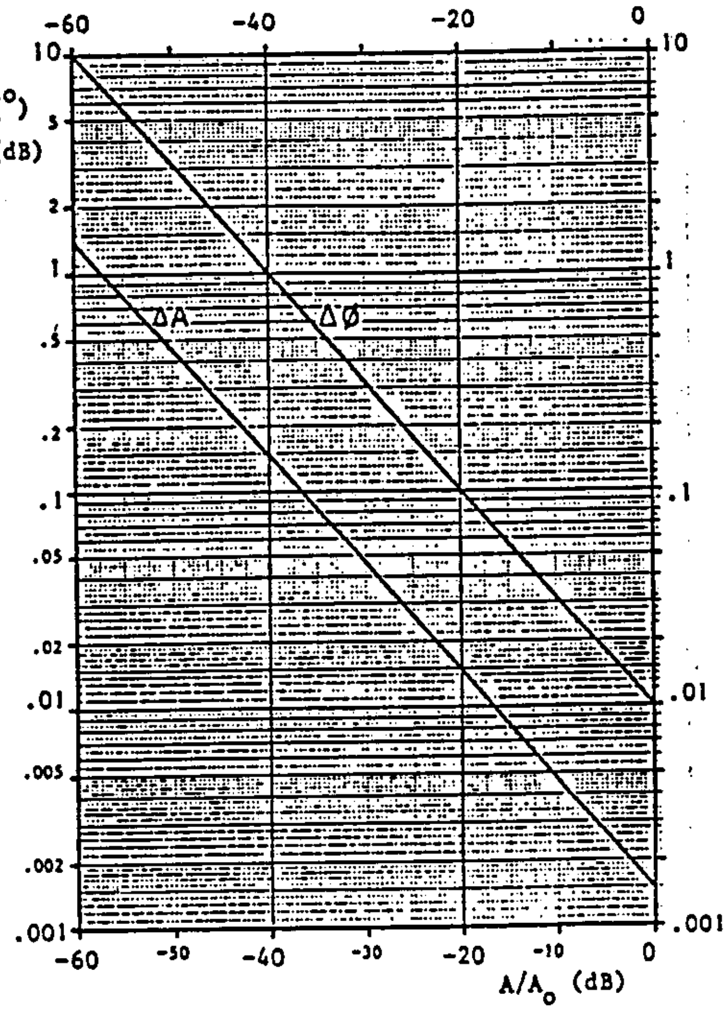
THE SAMPLING PROCESS

$$\Delta A = 10 \log \left(1 + 2\,\frac{K\sqrt{2} + 1}{K^2}\right)$$

$$\Delta\phi = \frac{\sqrt{2}}{K} \text{ rad}$$

$$M = 14$$

$$K = \frac{A}{A_0}\, 2^{M-1}$$



Worst case amplitude and phase resolution as a function of signal amplitude to full scale (coherent detection - 14 bit ideal A/D)

SATELLITE BEACON RECEIVERS

DIGITAL RECEIVERS

- Interest in digital receiver (DR) due to the potential accuracy and repeatability of this unit (0.2 dB and 2 deg required)
- Cost of the unit
- Performance of the receiver under deep fade conditions

In a conventional receiver:

the PLL band reduction has a limit in the phase noise characteristics of the signal beacon

Hysteresis to reacquire the beacon

loop threshold effects related to the (sinusoidal) non linearity of the phase detector

SATELLITE BEACON RECEIVERS

DIGITAL RECEIVERS (2)

In a DR only the carrier frequency is tracked. If phase measurement of the copolar/crosspolar components is required, this is performed via a separate process.

Advantage:

Phase noise produce less than 1 Hz rms frequency uncertainty
(5 Hz filter instead of 50 Hz)

Easy control of DR in fade conditions: freeze mode

In case of switched beacon, the DR has to track the satellite switching frequency (SWF). In this case, sampling frequency is multiple of satellite SWF.

SATELLITE BEACON RECEIVERS

THE ANALOGUE-DIGITAL COMBINED APPROACH

- In case of simple terminals, the DR is an expensive approach

- A combined analogue/digital approach, based on:

  - a banch of filters of narrow band
  - a low cost A/D converter

  could be a suitable approach.

The device ˆ was conceived for the Olumpus 20 GHz experiment.
It allows the measure of copolar and crosspolar amplitude
plus relative phase.

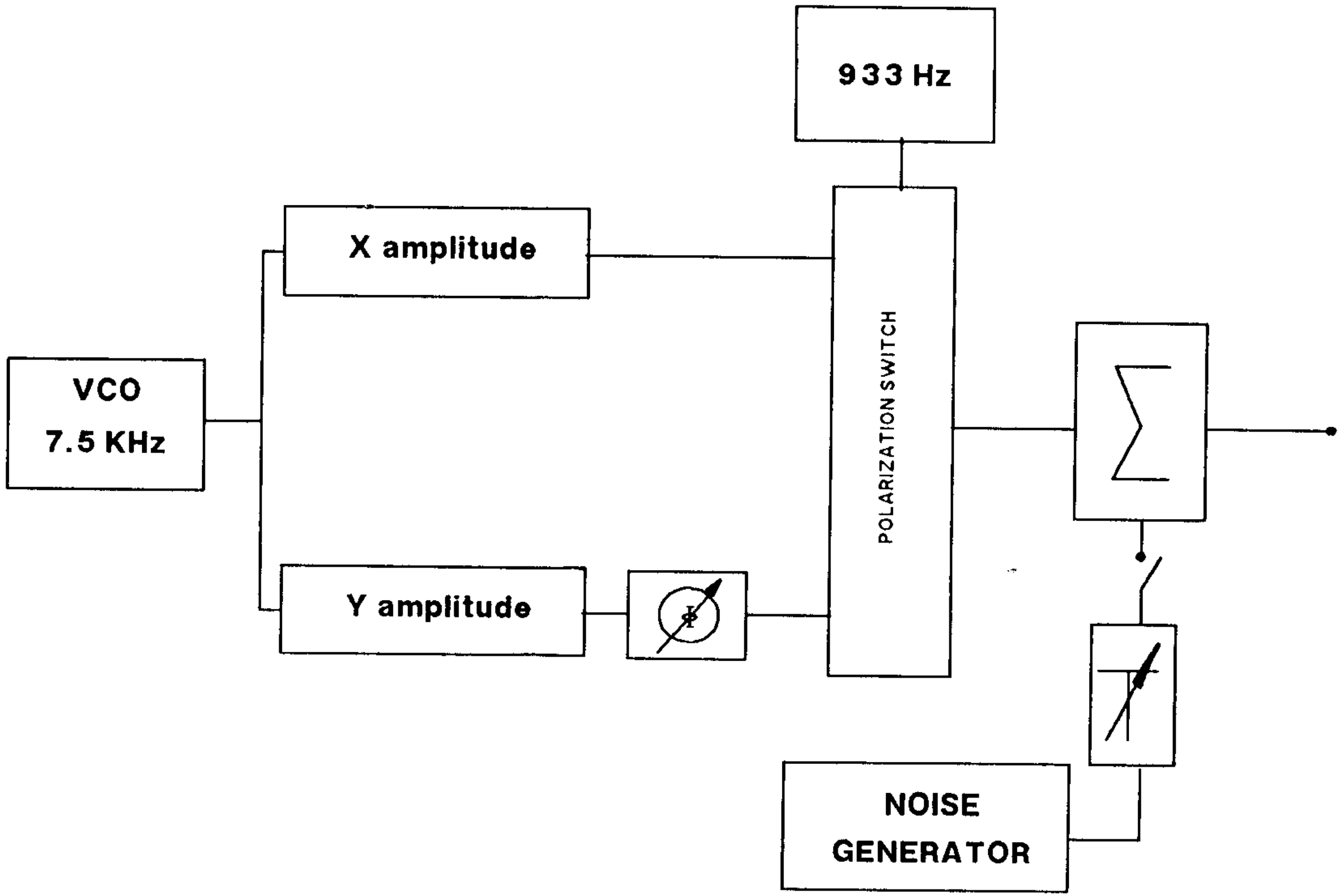
ˆ Patent pending by Teknel spa - Via Centuripe, 1 - 00179 Roma

TEKNEL SATELLITE BEACON RECEIVER

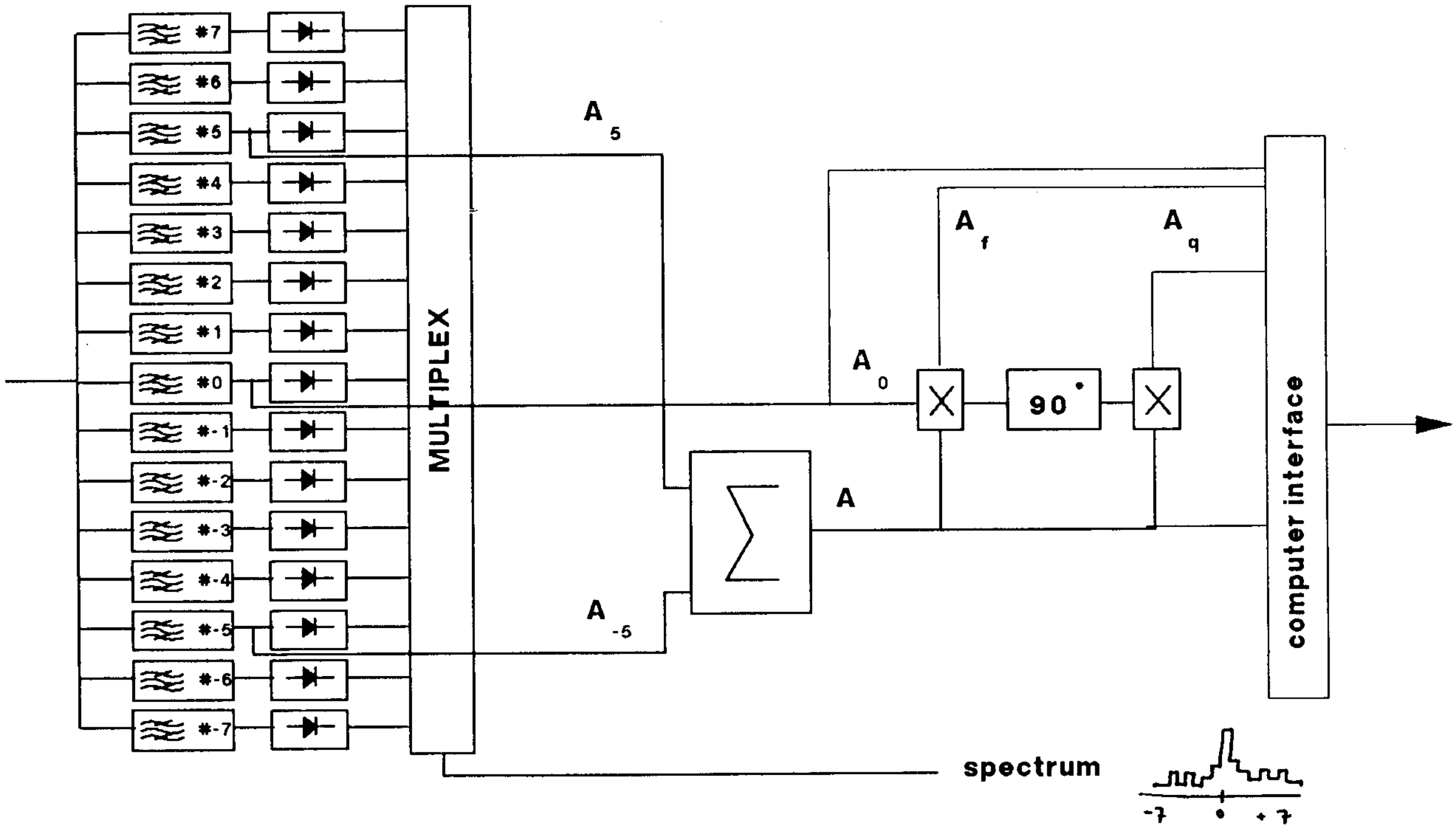
THEORY OF OPERATION

- Translation from 19.77 GHz to 7.5 KHz. The amplitude/phase relationship is mantained
- The 7.5 KHz feeds the filter bench (15 filters, BW = 183 Hz)
- r.m.s. detectors at the filter output. The receiver acts as a spectrum analyzer (Resolution BW = 183 Hz) but 15 times faster (highly useful during the searching phase)
- No threshold as the signal is detected even for S = N (if S = N then S + N = 3 dB over N)
- Phase information is the phase between the central carrier and the sum of the first components of lateral bands.

TEKNEL OLYMPUS BEACON SIMULATOR



TEKNEL OLYMPUS BEACON RECEIVER



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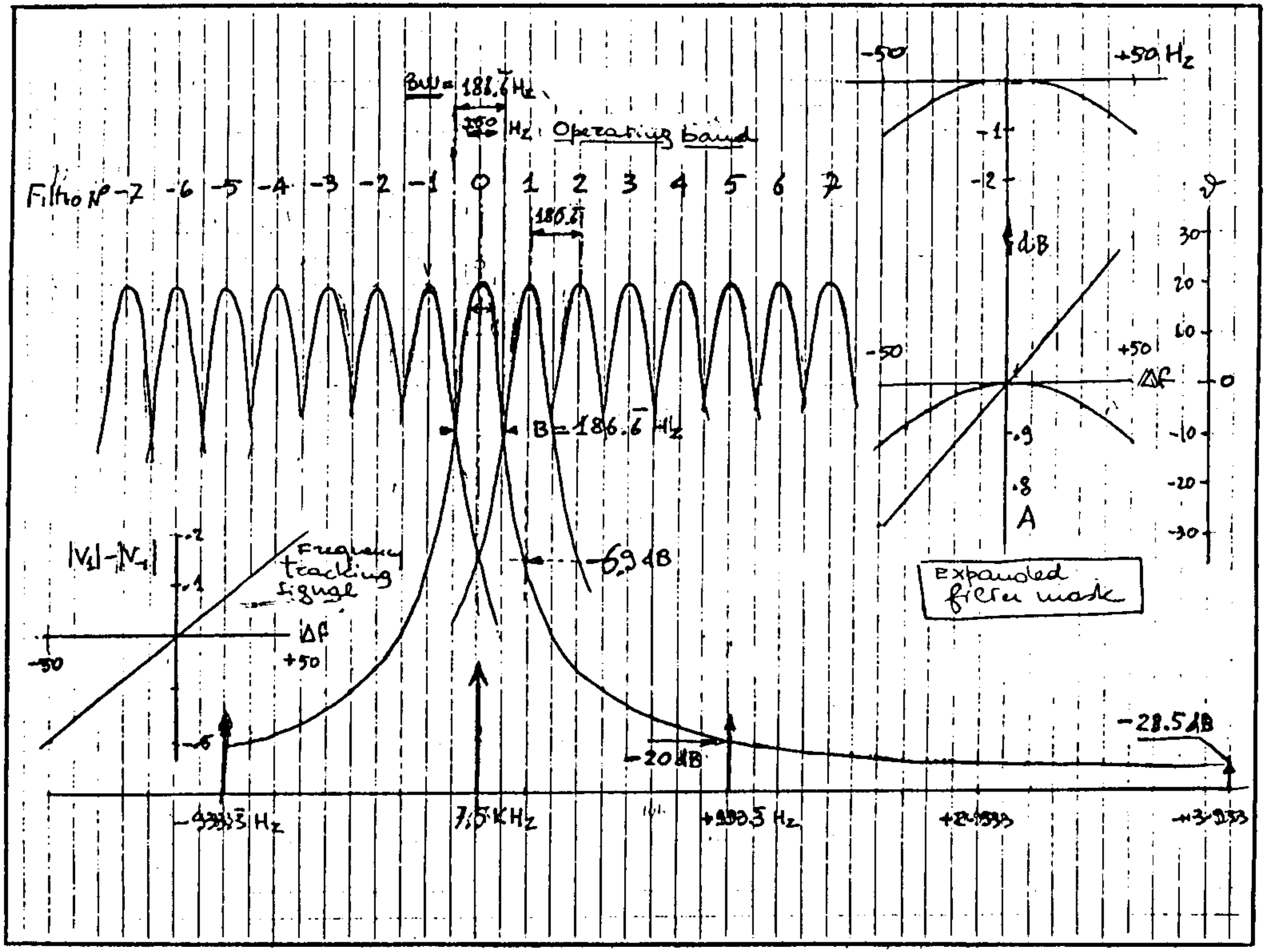
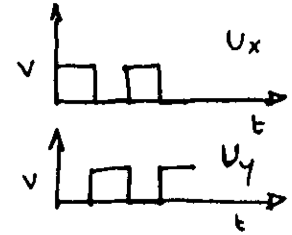
FILTER BENCH OVERALL MASK



FORMULAS UTILIZED FOR THE COMPUTATIONS



1) $U_x = \frac{1}{2} + \frac{2}{\pi}\left(\cos \Omega t - \frac{1}{3}\cos 3\Omega t + \frac{1}{5}\cos 5\Omega t \ldots\right)$

2) $U_y = \frac{1}{2} - \frac{2}{\pi}\left(\cos \Omega t - \frac{1}{3}\cos 3\Omega t + \frac{1}{5}\cos 5\Omega t \ldots\right)$

where :

$\Omega = 2\pi \cdot 933$ $\qquad \omega = 2\pi \cdot 7500$ $\quad$ (or $\omega = 2\pi \cdot 19.77\,GHz$)

COPOLAR SIGNAL $\quad S'_x = A_x U_x \cos \omega t$ $\qquad$ CROSSPOLAR SIGNAL $\quad S'_y = A_y U_y \cos(\omega t + \varphi)$

At the receiver input:

3) $S' = S'_x + S'_y = A_x U_x \cos \omega t + A_y U_y \cos(\omega t + \varphi)$

4) $S = \frac{A_x}{2}\cos \omega t + \frac{2}{\pi} A_x \cos \omega t \left(\cos \Omega t - \frac{1}{3}\cos 3\Omega t \ldots\right) + \frac{A_y}{2}\cos(\omega t - \varphi) - \frac{2}{\pi} A_y \cos(\omega t + \varphi)\left(\cos \Omega t - \frac{1}{3}\cos 3\Omega t \ldots\right)$

5) $S' = \left(\frac{A_x}{2} + \frac{A_y}{2}\cos\varphi\right)\cos \omega t - \frac{A_y}{2}\sin\varphi \sin \omega t + \frac{2}{\pi}\left[(A_x - A_y \cos\varphi)\cos \omega t \cdot \cos \Omega t - A_y \sin\varphi \sin \omega t \cos \Omega t\right) + \ldots$

CARRIER $\quad A_0^2 = \left(\frac{A_x}{2} + \frac{A_y}{2}\cos\varphi\right)^2 + \left(-\frac{A_y}{2}\right)^2 = \frac{1}{4}\left(A_x^2 + A_y^2 + 2A_xA_y\cos\varphi\right)$

MODULATION ENVELOPE $\quad A^2 = \frac{4}{\pi^2}\left(A_x - A_y\cos\varphi\right)^2 + \frac{4}{\pi^2}\left(A_y \sin\varphi\right)^2 = \frac{4}{\pi^2}\left(A_x^2 + A_y^2 - 2A_xA_y\cos\varphi\right)$

FORMULAS UTILIZED FOR THE COMPUTATIONS (2)

At the end of computations:

$$A_0 = \frac{1}{2}\sqrt{A_x^2 + A_y^2 + 2A_xA_y\cos\varphi}$$

$$A = \frac{2}{\pi}\sqrt{A_x^2 + A_y^2 - 2A_xA_y\cos\varphi}$$

$$A_f = \frac{A_x^2 - A_y^2}{\pi A_0}$$

$$A_q = \frac{2}{\pi}\cdot\frac{A_xA_y\sin\varphi}{A_0}$$

$$A_f^2 + A_q^2 = A^2$$

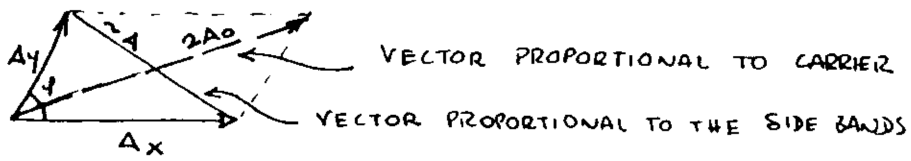
$$A = \frac{4}{\pi}\sqrt{\frac{A_x^2 + A_y^2}{2} - A_0}$$

$$\Rightarrow$$

$$A_x = \sqrt{\frac{2A_0^2 + \frac{\pi^2}{8}A^2 + \pi A_0A_f}{2}}$$

$$A_y = \sqrt{\frac{2A_0^2 + \frac{\pi^2}{8}A^2 - \pi A_0A_f}{2}}$$

$$tg\,\varphi = \frac{\frac{\pi}{2}A_0A_q}{A_0^2 - \frac{\pi^2}{16}A^2}$$



THE COMPUTER DISPLAY

BEACON RECEIVER OUTPUTS [V]				EVALUATION [V]			DIFFERENCE [dB]		
A0	A1	AF	AQ	AX	AY	AXY	DX	DY	DXY
+3.638	+1.336	+1.346	+0.153	+1.257	+0.170	+1.104	0.27	0.22	0.28
+3.636	+1.338	+1.348	+0.153	+1.257	+0.169	+1.106	0.27	0.18	0.29
#+3.634	+1.339	+1.348	+0.153	+1.257	+0.168	+1.107	0.27	0.18	0.29
+3.634	+1.337	+1.349	+0.153	+1.256	+0.168	+1.105	0.27	0.17	0.28
+3.640	+1.335	+1.349	+0.155	+1.257	+0.171	+1.104	0.27	0.22	0.28
+3.635	+1.336	+1.347	+0.152	+1.256	+0.169	+1.104	0.27	0.17	0.28
+3.636	+1.334	+1.347	+0.152	+1.256	+0.169	+1.103	0.26	0.18	0.27
+3.638	+1.335	+1.347	+0.155	+1.256	+0.170	+1.104	0.27	0.25	0.28
+3.633	+1.336	+1.345	+0.156	+1.256	+0.169	+1.104	0.27	0.20	0.28
+3.634	+1.336	+1.346	+0.154	+1.256	+0.169	+1.105	0.27	0.21	0.28
+3.632	+1.336	+1.347	+0.152	+1.255	+0.168	+1.104	0.26	0.19	0.27
+3.638	+1.337	+1.348	+0.154	+1.257	+0.169	+1.105	0.28	0.16	0.29
+3.636	+1.336	+1.346	+0.154	+1.256	+0.169	+1.105	0.27	0.21	0.28
+3.636	+1.337	+1.351	+0.155	+1.257	+0.169	+1.105	0.28	0.21	0.29

Simulator outputs   Ax 1.18   Ay 0.161   Phi 24.3°   20*log(Ax/Ay)   +17.3

Measured/evaluated parameters difference

Parameters evaluated from simulator outputs

Voltages measured by the computer at the beacon simulator outputs

Voltages measured by the computer at the receiver outputs