

**The System Design of a Radar Track-While-Scan Facility
Utilizing Modern Digital Techniques**

Michael Senery.

A project report submitted to the Faculty of Engineering,
University of the Witwatersrand, Johannesburg, in partial
fulfilment of the requirements for the degree of Master
of Science in Engineering.

Johannesburg 1985.

Declaration.

I declare that this project report is my own undivided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

.....


(Signature)

1st day of September 1985.

Abstract

The system design of a Track-While-Scan facility for a small surveillance radar is presented. The reader is introduced to Track-While-Scan concepts and a brief review of tracking filters is given. A particular system requirement is detailed and the design of a Track-While-Scan system is described using an available personal computer to implement the digital processing.

Dedication.

ACKNOWLEDGEMENTS

The author would like to thank the following for permission to

To my mother and late father.

utilize the following for the design and

Jean and William Henery.

representation of the project and for permission to publish this

report.

Acknowledgements.

The author would like to thank E.S.D (Pty) Ltd for permission to utilise the equipment necessary for the design and implementation of the project and for permission to publish this report.

2.1.1	Introduction to Tracking Filters	26
2.1.2	Track Initiation	27
2.1.3	Termination of Track	28
2.1.4	Track Updating	29
2.1.5	Track Association	30
2.1.6	Track Deletion	31
2.1.7	Track Maintenance	32
2.1.8	Track Management	33
2.1.9	Track Initiation and Termination	34
2.1.10	Track Updating and Association	35
2.1.11	Track Deletion	36
2.1.12	Track Maintenance	37
2.1.13	Track Management	38
2.1.14	Track Initiation and Termination	39
2.1.15	Track Updating and Association	40
2.1.16	Track Deletion	41
2.1.17	Track Maintenance	42
2.1.18	Track Management	43
2.1.19	Track Initiation and Termination	44
2.1.20	Track Updating and Association	45
2.1.21	Track Deletion	46
2.1.22	Track Maintenance	47
2.1.23	Track Management	48
2.1.24	Track Initiation and Termination	49
2.1.25	Track Updating and Association	50
2.1.26	Track Deletion	51
2.1.27	Track Maintenance	52
2.1.28	Track Management	53
2.1.29	Track Initiation and Termination	54
2.1.30	Track Updating and Association	55
2.1.31	Track Deletion	56
2.1.32	Track Maintenance	57
2.1.33	Track Management	58
2.1.34	Track Initiation and Termination	59
2.1.35	Track Updating and Association	60
2.1.36	Track Deletion	61
2.1.37	Track Maintenance	62
2.1.38	Track Management	63
2.1.39	Track Initiation and Termination	64
2.1.40	Track Updating and Association	65
2.1.41	Track Deletion	66
2.1.42	Track Maintenance	67
2.1.43	Track Management	68
2.1.44	Track Initiation and Termination	69
2.1.45	Track Updating and Association	70
2.1.46	Track Deletion	71
2.1.47	Track Maintenance	72
2.1.48	Track Management	73
2.1.49	Track Initiation and Termination	74
2.1.50	Track Updating and Association	75
2.1.51	Track Deletion	76
2.1.52	Track Maintenance	77
2.1.53	Track Management	78
2.1.54	Track Initiation and Termination	79
2.1.55	Track Updating and Association	80
2.1.56	Track Deletion	81
2.1.57	Track Maintenance	82
2.1.58	Track Management	83
2.1.59	Track Initiation and Termination	84
2.1.60	Track Updating and Association	85
2.1.61	Track Deletion	86
2.1.62	Track Maintenance	87
2.1.63	Track Management	88
2.1.64	Track Initiation and Termination	89
2.1.65	Track Updating and Association	90
2.1.66	Track Deletion	91
2.1.67	Track Maintenance	92
2.1.68	Track Management	93
2.1.69	Track Initiation and Termination	94
2.1.70	Track Updating and Association	95
2.1.71	Track Deletion	96
2.1.72	Track Maintenance	97
2.1.73	Track Management	98
2.1.74	Track Initiation and Termination	99
2.1.75	Track Updating and Association	100

Table Of Contents

1.0	INTRODUCTION	15
1.1	Present System	16
1.2	Design Aims	17
1.3	Report Structure	19
2.0	WHAT IS TRACK-WHILE-SCAN	20
2.1	Surveillance Radars	20
2.2	Tracking Radars	22
2.3	The Track-While-Scan-System	22
2.4	TWS Process Stages	25
2.4.1	Target Detection	25
2.4.2	Target Acquisition And Tracking Windows	26
2.5	Track Initiation	27
2.5.1	Resolution Of Track Ambiguity	29
2.5.2	Track Filtering And Prediction	30
2.6	The Basic TWS System	31
3.0	THE TRACKING FILTERS	32
3.1	How The Target Is Tracked	32
3.2	Basic Concepts Of Tracking Filters	34
3.2.1	The Tracking Model	34
3.2.2	Linearity And Coordinate Translations	35
3.2.3	Filter Memory Types	36
3.3	Review Of Tracking Filters	37
3.3.1	The Alpha Filter	38
3.3.2	The Alpha-Beta Filter	40
3.3.2.1	The Discounted Least Squares Alpha-Beta Filter	44
3.3.2.2	The Benedict - Bordner Alpha-Beta Filter	46

3.3.2.3	The Expanding Memory Alpha-Beta Filter . . .	47
3.3.2.4	Adaptive Alpha-Beta Filters	49
3.3.3	The Alpha-Beta-Gamma Filter	50
3.3.4	The Kalman Filter	51
3.4	Tracking Filter Design	56
4.0	HOW THE TARGET IS TRACKED	58
4.1	The Tracking System	58
4.2	Target Designation	58
4.3	Track Initiation	59
4.3.1	Opening The Track File	60
4.3.2	Setting Up The Acquisition Window	61
4.4	Track Predication	62
4.4.1	The Mean Of The Extremeties Algorithm	64
4.4.2	The Mean Range And Azimuth Position	65
4.4.3	Weighted Echoes Method	67
5.0	THE SYSTEM DESIGN	68
5.1	Integration Into The Present Radar System . . .	68
5.2	Man-Machine Interface	69
5.3	The Window Generator	72
5.4	Number Of Targets To Be Tracked	72
5.5	Target Parameters	73
5.6	Window Sizes	73
5.7	Choice Of Tracking Filter	75
5.8	Tracking Filter Initialisation	77
5.9	Track Ambiguity Algorithm.	78
6.0	SYSTEM IMPLEMENTATION	79
6.1	The PPI Display	79
6.1.1	The X And Y Deflection Voltage Generators . .	79

6.1.2	The Z-Modulation Generating Circuitry	82
6.2	The Joystick Interface	87
6.3	The Symbol Generating And Positioning Circuitry	89
6.4	The Track-While-Scan-Processor	99
6.4.1	The Window Generator	99
6.4.1.1	The Memory Card	102
6.4.2	The TWS Algorithm	105
6.4.2.1	The Setup Process And Main Calling Routine .	105
6.4.2.2	The Initiate Routine	108
6.4.2.3	The Cancel Routine	113
6.4.2.4	The Track Routine	114
6.5	The TWS Program	116
7.0	SYSTEM CONSTRUCTION	117
7.1	PPI Drive Circuit And Symbol Position Generator Circuit	117
7.2	TWS Window Generator And Memory Card	120
8.0	SYSTEM PERFORMANCE	123
8.1	Predicted Results	123
8.2	Method Of Obtaining Results	124
8.3	System Performance	125
9.0	DISCUSSION	129
10.0	REFERENCES	131

APPENDIX A BRIEF DESCRIPTION OF THE PRESENT RADAR OPERATION

APPENDIX B CHARACTERISTICS OF THE PRESENT RADAR SYSTEM

APPENDIX C EXPECTED TARGET PARAMETERS

C.1	MILITARY AIRCRAFT	C-2
C.2	CIVILIAN AIRCRAFT	C-2
C.2.1	Jet Aircraft	C-3
C.2.2	Propeller Aircraft	C-3

APPENDIX D MATHEMATICAL DERIVATION OF THE ACQUISITION WINDOW SIZE

APPENDIX E EXPECTED NUMBER OF ECHOES RECEIVED FROM A TARGET

APPENDIX F THE SYMBOL GENERATOR CIRCUIT

APPENDIX G THE WINDOW GENERATOR CIRCUIT

APPENDIX H THE MEMORY CARD

APPENDIX I SOFTWARE LISTING OF THE TWS PROGRAM

I.1	THE SETUP PROCEDURE	I-2
I.2	THE MAIN CALLING PROGRAM	I-2
I.3	THE TRACKING ROUTINE	I-3
I.4	THE INITIATE ROUTINE	I-6
I.5	THE CANCEL ROUTINE	I-7
I.6	THE SYMBOL OUTPUT SUBROUTINE	I-8

I.7 THE WINDOW OUTPUT SUBROUTINE I-9

1.1	The output of a typical PPI display	21
1.2	The output of a typical PPI display with a target	22
1.3	A PPI display with a target and a window	23
1.4	View of the window	24
1.5	Block diagram of a typical PPI system	31
1.6	General schematic of a tracking filter system	33
1.7	Filter memory organization	37
1.8	The Alpha filter	39
1.9	The Alpha-Beta filter	42
1.10	The Alpha-Beta filter's stability region	43
1.11	The Alpha-Beta filter's response regions	45
1.12	Logic for the cascaded Alpha-Beta filter	46
1.13	Logic for the cascaded Alpha-Beta filter	46
1.14	Plot of Alpha-Beta versus X for the cascaded	46
1.15	Memory filter	48
1.16	A general form of the Kalman filter	51
1.17	Computational steps in the Kalman filter	53
1.18	Computational steps in the Kalman filter	55
1.19	Algorithm for the Kalman filter	57
1.20	Algorithm for the Kalman filter	58
1.21	Algorithm for the Kalman filter	59
1.22	Algorithm for the Kalman filter	60
1.23	Algorithm for the Kalman filter	61
1.24	Algorithm for the Kalman filter	62
1.25	Algorithm for the Kalman filter	63
1.26	Algorithm for the Kalman filter	64
1.27	Algorithm for the Kalman filter	65
1.28	Algorithm for the Kalman filter	66
1.29	Algorithm for the Kalman filter	67
1.30	Algorithm for the Kalman filter	68
1.31	Algorithm for the Kalman filter	69
1.32	Algorithm for the Kalman filter	70
1.33	Algorithm for the Kalman filter	71
1.34	Algorithm for the Kalman filter	72
1.35	Algorithm for the Kalman filter	73
1.36	Algorithm for the Kalman filter	74
1.37	Algorithm for the Kalman filter	75
1.38	Algorithm for the Kalman filter	76
1.39	Algorithm for the Kalman filter	77
1.40	Algorithm for the Kalman filter	78
1.41	Algorithm for the Kalman filter	79
1.42	Algorithm for the Kalman filter	80
1.43	Algorithm for the Kalman filter	81
1.44	Algorithm for the Kalman filter	82
1.45	Algorithm for the Kalman filter	83
1.46	Algorithm for the Kalman filter	84
1.47	Algorithm for the Kalman filter	85
1.48	Algorithm for the Kalman filter	86
1.49	Algorithm for the Kalman filter	87
1.50	Algorithm for the Kalman filter	88
1.51	Algorithm for the Kalman filter	89
1.52	Algorithm for the Kalman filter	90
1.53	Algorithm for the Kalman filter	91
1.54	Algorithm for the Kalman filter	92
1.55	Algorithm for the Kalman filter	93
1.56	Algorithm for the Kalman filter	94
1.57	Algorithm for the Kalman filter	95
1.58	Algorithm for the Kalman filter	96
1.59	Algorithm for the Kalman filter	97
1.60	Algorithm for the Kalman filter	98
1.61	Algorithm for the Kalman filter	99
1.62	Algorithm for the Kalman filter	100
1.63	Algorithm for the Kalman filter	101
1.64	Algorithm for the Kalman filter	102
1.65	Algorithm for the Kalman filter	103
1.66	Algorithm for the Kalman filter	104
1.67	Algorithm for the Kalman filter	105
1.68	Algorithm for the Kalman filter	106
1.69	Algorithm for the Kalman filter	107
1.70	Algorithm for the Kalman filter	108
1.71	Algorithm for the Kalman filter	109
1.72	Algorithm for the Kalman filter	110
1.73	Algorithm for the Kalman filter	111
1.74	Algorithm for the Kalman filter	112
1.75	Algorithm for the Kalman filter	113
1.76	Algorithm for the Kalman filter	114
1.77	Algorithm for the Kalman filter	115
1.78	Algorithm for the Kalman filter	116
1.79	Algorithm for the Kalman filter	117
1.80	Algorithm for the Kalman filter	118
1.81	Algorithm for the Kalman filter	119
1.82	Algorithm for the Kalman filter	120
1.83	Algorithm for the Kalman filter	121
1.84	Algorithm for the Kalman filter	122
1.85	Algorithm for the Kalman filter	123
1.86	Algorithm for the Kalman filter	124
1.87	Algorithm for the Kalman filter	125
1.88	Algorithm for the Kalman filter	126
1.89	Algorithm for the Kalman filter	127
1.90	Algorithm for the Kalman filter	128
1.91	Algorithm for the Kalman filter	129
1.92	Algorithm for the Kalman filter	130
1.93	Algorithm for the Kalman filter	131
1.94	Algorithm for the Kalman filter	132
1.95	Algorithm for the Kalman filter	133
1.96	Algorithm for the Kalman filter	134
1.97	Algorithm for the Kalman filter	135
1.98	Algorithm for the Kalman filter	136
1.99	Algorithm for the Kalman filter	137
1.100	Algorithm for the Kalman filter	138

List of Figures

2.1	The output of a typical PPI display	21
2.2	The output of a typical A-Scope display	23
2.3	A PPI display with TWS symbols included	24
2.4	View of the windows	28
2.5	Block diagram of a typical TWS system	31
3.1	General schematic of a tracking filter system . . .	33
3.2	Filter memory types	37
3.3	The Alpha filter	39
3.4	The Alpha-Beta filter	42
3.5	The Alpha-Beta filter stability region	42
3.6	The Alpha-Beta filter response regions	43
3.7	Locus for the critically damped Alpha-Beta filter .	45
3.8	Locus for the Benedict-Bordner condition	46
3.9	Plot of Alpha, Beta versus N for the Expanding Memory filter	48
3.10	A general form of the Kalman filter	53
3.11	Computational stages in the Kalman filter	55
3.12	Computational steps in the Kalman filter	55
4.1	A possible set of echo returns within the window .	63
4.2	Measured target position using the Mean of the Extremities algorithm	65
4.3	Measured target position using the Mean Range and Azimuth algorithm	66
5.1	Timing diagram of the signals output by the signal processor	68

5.2	Plot of Alpha, Beta versus N for the filter chosen .	77
6.1	Block diagram of the deflection voltage generating circuitry	80
6.2	The analog sweep voltages	83
6.3	Block diagram of the video Z-modulation generating circuitry	84
6.4	The analog sweep voltages with the Z-modulation signal	86
6.5	Block diagram of the joystick position input device	88
6.6	The PPI display and the overlay grid	90
6.7	How the signal is built up	91
6.8	Basic block diagram of the symbol positioning and generating circuitry	93
6.9	The analog symbol voltages	95
6.10	Block diagram of the symbol Z-modulation generating circuitry	97
6.11	The analog symbol voltages with the Z-modulation signal	96
6.12	The composite X,Y deflection voltages with the Z-modulation signal	98
6.13	How the window is constructed	100
6.14	Basic block diagram of the window generating circuitry	101
6.15	Basic block diagram of the memory card	104
6.16	An overview of the TWS program	106
6.17	Main calling routine	107
6.18	Initiate routine	109

6.19	Symbol positioning subroutine	110
6.20	Window positioning subroutine	111
6.21	Cancel routine	113
6.22	Track routine	115
7.1	Example of a digital wire-wrap card	119
7.2	Example of an analog printed circuit board	119
7.3	The 19" rack system	120
7.4	The window generator and memory cards	122
7.5	The IBM PC with dedicated cards installed	122
8.1	Typical PPI display showing track sequence	123
8.2	System PPI display	126
8.3	Target track on the system PPI display	127
A.1	Block diagram of the radar receiver and transmitter sections	A-3
A.2	Block diagram of the typical signal processor	A-5
A.3	Block diagram of the basic MTI filter	A-6
A.4	MTI filter response	A-8
A.5	Block diagram of the m-out-of-n detector	A-9
A.6	Block diagram of the cell-averaging CFAR detector	A-10
A.7	Typical antenna elevation coverage patterns	A-12
D.1	Radial acceleration on a body	D-3
D.2	Radial flight: possible flight paths	D-5
D.3	Tangential flight: possible flight paths	D-6
D.4	Window dimensions	D-7
E.1	Antenna pattern and target interaction	E-3

F.1	Block diagram of the symbol positioning and generating circuitry	F-3
G.1	Block diagram of the window generating circuitry	G-3
G.2	Timing diagram for the halting circuit	G-2
H.1	Block diagram of the memory card	H-3
I.1	Setup procedure	I-2
I.2	Main calling routine	I-3
I.3	Tracking routine	I-4
I.4	Initiate routine	I-6
I.5	Cancel routine	I-8
I.6	Symbol positioning subroutine	I-8
I.7	Window positioning subroutine	I-9

1.0 INTRODUCTION

Surveillance radars are widely used both in civilian and military applications to provide airspace cover around airfields, point targets and demarcated areas.

These radars provide elevation coverage as determined by the antenna vertical radiation pattern and, in general, full azimuth coverage.

All targets within this volume of coverage are then displayed. It is up to the operator to identify the status of the targets (friendly or enemy) and to monitor the flight paths of these targets.

Tracking radars, in contrast, are used to track a particular target in three-dimensional space and to supply the target position to, say, a gun or missile system. These radars do not provide coverage over a large area and usually form part of a defensive system.

A facility that would combine the wide coverage of the surveillance radar with the ability to provide particular target tracks is called a Track-While-Scan system. This system will allow the radar to operate as a normal surveillance radar displaying all targets within the area and in addition allows the operator to designate targets to be tracked. The Track-While-Scan system would then extract the target position

from the radar system and make predictions as to where the target will be expected to lie on the following scan. Tracking algorithms are employed to implement this prediction. The predicted position is indicated on the surveillance radar display and if necessary may be output to a gun or missile system. Multiple targets may thus also be tracked.

1.1 Present System

A ground-based surveillance radar capable of detecting aircraft to a maximum range of 15km has been built, based on a commercially available marine radar. The modifications to the original radar include an improvement to the receiver, the development of new timing circuits and a digital signal processor.

The digital signal processor consists of two Analog-to-Digital converters, a digital Moving Target Indicator filter and associated Vector Adder and a Constant False Alarm Rate detector.

The signal emerging from the signal processor is one-bit video and may be termed the primary video signal. This primary video signal is passed onto the Plan Position Indicator display for the output of the radar data.

The original Plan Position Indicator display has been left

untouched.

Appendix A contains a brief description of surveillance radar operation.

Appendix B lists the characteristics of the present radar system.

1.2 Design Aims

There presently exists a short-range surveillance radar for which no Track-While-Scan facility is available.

In order for the operator to designate targets and for the Track-While-Scan processor to indicate the target tracks on the display some means must be made available to allow the system to write the information to the display. This Track-While-Scan data is termed the synthetic video signal. The present Plan Position Indicator display does not allow the inclusion of any synthetic video at all.

The first design aim was to implement a new display capable of displaying the synthetic video signals as well as the primary video signal. The particular choice of display had not been finalised so the driving circuitry had to be capable of being interfaced to a wide variety of commercially available X-Y-Z vector-type displays. The requirement for displaying up to

three target tracks and a designation marker was catered for.

Most literature available on the subject of Track-While-Scan systems tends to concentrate on the simulated performances of the various tracking algorithms and few, if any, have concentrated on the implementation of a system. In order to demonstrate that a working system may be constructed a particular type of tracking algorithm, namely the Benedict-Bordner Alpha-Beta Filter with an exponentially decaying value of alpha was implemented using an IBM PC to execute the program and dedicated hardwired logic to interface the IBM PC to the radar. This allowed the system to be demonstrated for single track operation. Further work would then involve an investigation into the feasibility of tracking multiple targets using a single-board computer to implement the tracking algorithms.

An IBM PC was chosen to implement the Track-While-Scan processor for the following reasons:

1. It allowed the development and debugging of the algorithm to be implemented in a high level language.
2. A single board computer was unavailable.
3. The aim was to investigate the viability of using a small processor to implement the Track-While-Scan system.

1.3 Report Structure

The first section of the report looks at the Track-While-Scan process in detail and describes the various stages in the tracking process. As was mentioned earlier a tremendous amount has been written on the performance analysis of the various tracking algorithms. An introduction to the method of tracking is detailed as well as a brief review of the various types of tracking algorithms. These sections deal primarily with the theory involved in Track-While-Scan processes and numerous works on the subject are referenced.

The system requirement is then detailed and typical aircraft performance figures are quoted, around which the system is to be designed. This is followed by a detailed description of the expected system operation and the exact implementation of every unit within the system is described.

Once the system was built it was tested and found to work successfully. The typical target types and flight paths were investigated and photographic evidence is presented to substantiate the conclusions.

2.0 WHAT IS TRACK-WHILE-SCAN

2.1 Surveillance Radars

If the volume of airspace surrounding an airfield or a particular area is to be scanned continuously for aircraft then use is made of a surveillance radar. The antenna beamshape provides the elevation pattern coverage as well as the narrowbeam azimuth pattern coverage and the antenna is made to scan in a full three hundred and sixty degree azimuth circle. The range at which aircraft are detected is limited in part by the transmitted power of the radar and the rate at which the radar pulses are transmitted. Some of the newer and certainly more expensive radars may make use of a Chirp waveform to provide a limited estimate of aircraft altitude, but in general surveillance radars are two dimensional sensors, the two dimensions being range and azimuth.

The position of the target relative to the radar may be displayed on a Plan Position Indicator (PPI) display. A typical view of a PPI display output is illustrated in figure 2.1.

Point clutter sources or clutter breakthrough from the Moving Target Indicator (MTI) filter appear as small illuminated areas on the display. The actual antenna position is indicated by the radial line formed by the range ring indicators. The range rings provide the operator with a rough indication of the distance to the target. The target movement is normally easy to

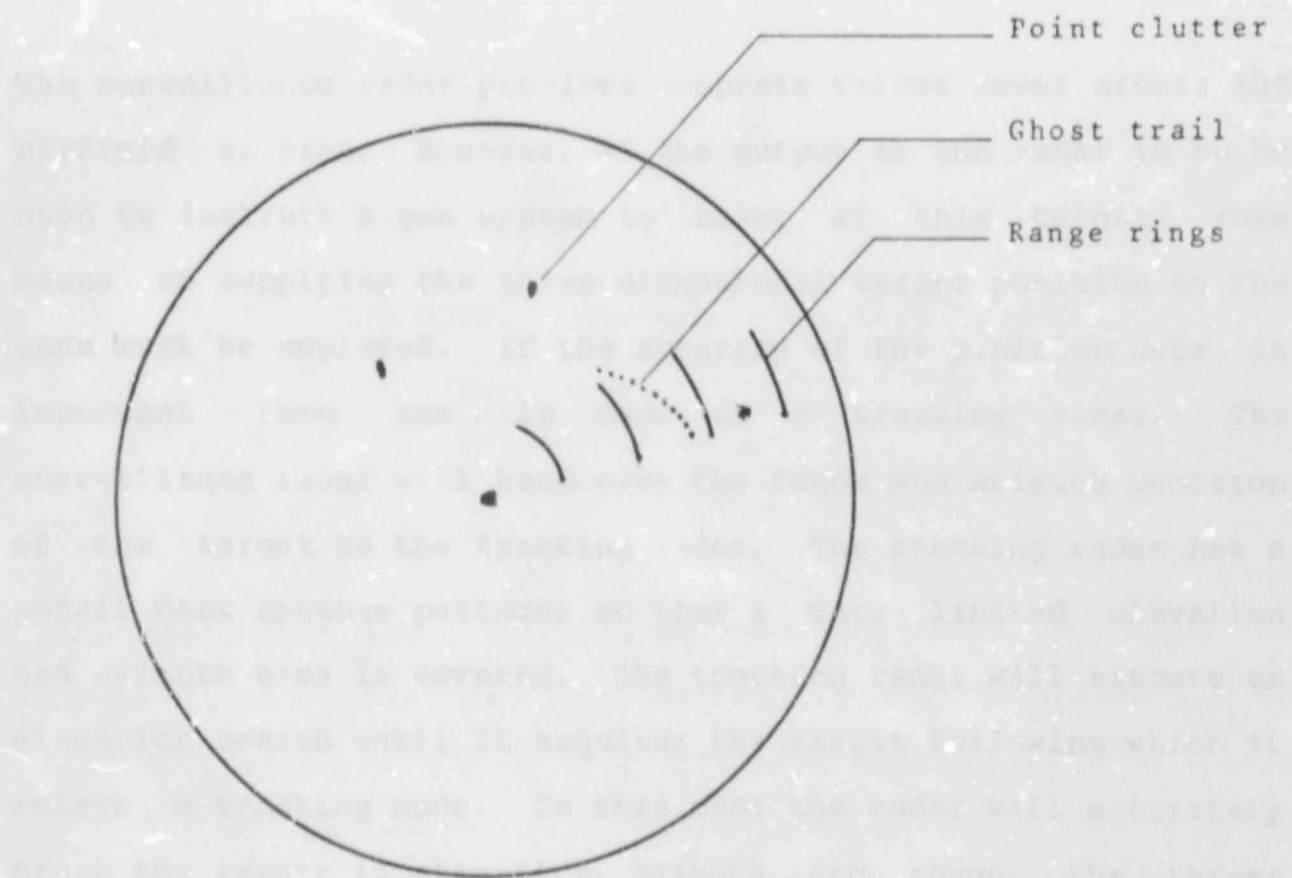


Figure 2.1 The Output of a Typical PPI Display

spot: as the target moves through the air, the sweep will illuminate successive positions on the PPI display. The previous positions are not illuminated but because of the persistence of the display one can see the older target positions. This "track" is referred to as a ghost trail, the length of this trail being dependent on the particular persistence of the PPI display phosphor.

Author Henery Michael

Name of thesis The System Design Of A Radar Track-while-scan Facility Utilizing Modern Digital Techniques. 1985

PUBLISHER:

University of the Witwatersrand, Johannesburg

©2013

LEGAL NOTICES:

Copyright Notice: All materials on the University of the Witwatersrand, Johannesburg Library website are protected by South African copyright law and may not be distributed, transmitted, displayed, or otherwise published in any format, without the prior written permission of the copyright owner.

Disclaimer and Terms of Use: Provided that you maintain all copyright and other notices contained therein, you may download material (one machine readable copy and one print copy per page) for your personal and/or educational non-commercial use only.

The University of the Witwatersrand, Johannesburg, is not responsible for any errors or omissions and excludes any and all liability for any errors in or omissions from the information on the Library website.