Practical Measurements Improve UHF Yagi Antennas

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Contents

- Customer-focussed project to upgrade an antenna design to meet CAI/DTG requirements for Freeview reception
  - *Familiarisation with these requirements*
- Development of techniques for measurement and optimisation of gain, directivity, return loss
  - *Three-antenna method, indoor and outdoor measurements*
- Involved redesign of dipole and balun, re-optimisation of director elements

CAI Benchmarking for Digital Terrestrial Broadcast Antennas

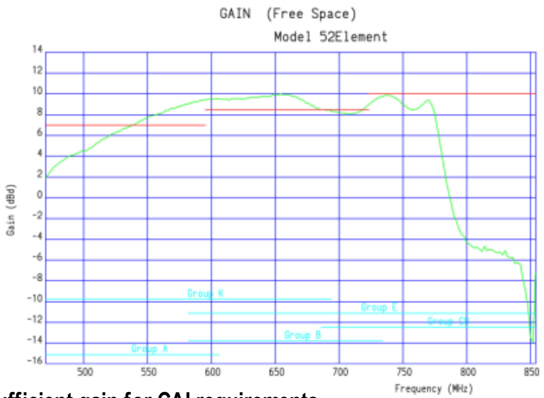
- Confederation of Aerial Industries and Digital TV Group have created a benchmarking scheme in conjunction with BBC and interested parties
- Concerned with improving the quality of UK DTT aerial installations
- Standard 1, 2, 3, 4 categories according to:
  - *Bandwidth*
  - *Gain*
  - *Return Loss*
  - *Directivity*
  - *Interference Immunity*
  - *Cross-Polar Isolation*

Target of Standard 2 Band W

AERIAL STANDARD	GROUP 'A' (CH21-37)	GROUP 'B' (CH35-53)	GROUP 'CD' (CH48-68)	GROUP 'E' (CH35-68)		GROUP 'K' (CH21-48)		GROUP 'W' (CH21-68)		
				CHANNEL 35-47	CHANNEL 48-68	CHANNEL 21-36	CHANNEL 37-48	CHANNEL 21-36	CHANNEL 37-52	CHANNEL 53-68
1	10	11	12	11	12	10	11	10	11	12
2	7.5	8.5	10	8.5	10	7.5	8.5	7	8.5	10
3	6	7	8	7	8	6	7	5	7	8
4	Not applicable							7	7	7

Parameter	Channel 21 -36	Channel 37 - 52	Channel 53 - 68
Forward gain 2.15 dB must be added to give the gain in dBi.	7 dBd	8.5 dBd	10 dBd
Directivity (E-plane only)	16dB max sidelobes at > 75° from boresight		
Return loss	6 dB		
Cross-Polar Protection	15 dB		
Feeder pick-up rejection	9 dB		

Initial Approval Results



- Insufficient gain for CAI requirements

Three-Antenna Gain Method

$$P_r = P_t G_r G_t \left(\frac{\lambda}{4\pi r}\right)^2$$

$$L_{rt} = \frac{P_r}{P_t} = |S_{21}|^2$$

$$let \quad \left(\frac{\lambda}{4\pi r}\right)^2 = k$$

for antennas 1,2,3 :

$$L_{12} = G_1 G_2 k$$

$$L_{23} = G_2 G_3 k$$

$$L_{31} = G_3 G_1 k$$

$$\therefore L_{23} = \frac{L_{12}}{G_1 k} \cdot \frac{L_{31}}{G_1 k} \cdot k$$

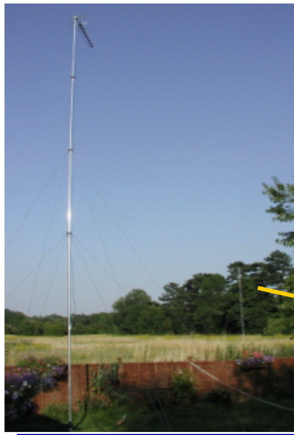
$$G_1^2 = \frac{L_{12} L_{31}}{L_{23} k}$$

- Received power depends on transmitted power, antenna gain and free space propagation law
- Let L_{rt} be loss between antennas
- Measurements of loss between each combination of three antennas
- Solve simultaneous equations to yield gain of individual antennas
- Deduct 2.15 dB to get from dBi to dBd

Practical Measurements

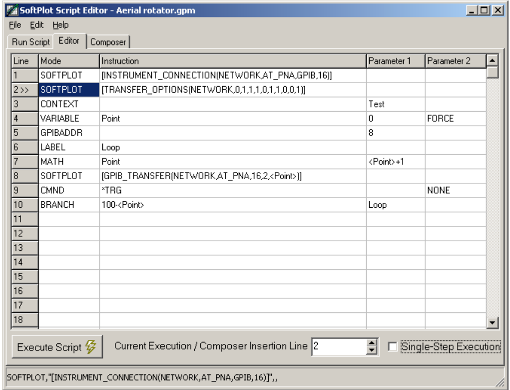
- Open field test site
- 10 m telescopic masts
- 50 m antenna separation
- VNA with 12-term Calibration in 75 ohm F-type (note long cable makes a good 75-ohm pad!)
- Aerial rotator on one of the masts to provide antenna pattern measurements

Practical Measurements



- Pulsed relay powers rotator for 1 second increments
- Script sequences rotation and gathering of S21 sweeps
- Processing of results into directivity and gain plots

Aerial Rotator Script

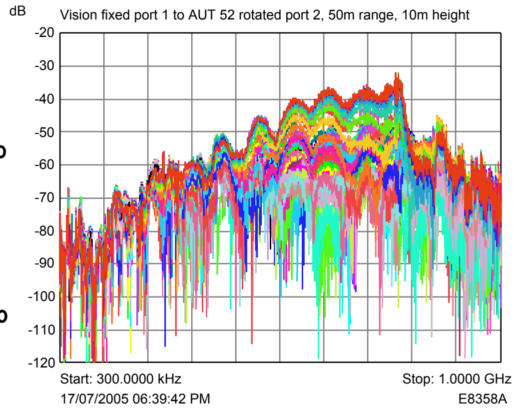


Line	Mode	Instruction	Parameter 1	Parameter 2
1	SOFTPLOT	[INSTRUMENT_CONNECTION(NETWORK,AT_PNA,GPIB,16)]		
2 >>	SOFTPLOT	[TRANSFER_OPTIONS(NETWORK,0,1,1,1,0,1,1,0,0,1)]		
3	CONTEXT		Test	
4	VARIABLE	Point	0	FORCE
5	GPIBADDR		8	
6	LABEL	Loop		
7	MATH	Point	<Point>+1	
8	SOFTPLOT	[GPIB_TRANSFER(NETWORK,AT_PNA,16,2,<Point>)]		
9	CMND	*TRG		NONE
10	BRANCH	100-<Point>	Loop	
11				
12				
13				
14				
15				
16				
17				
18				

- A mix of SoftPlot automation (recorded when manually initiating a measurement), and triggering the pulse generator

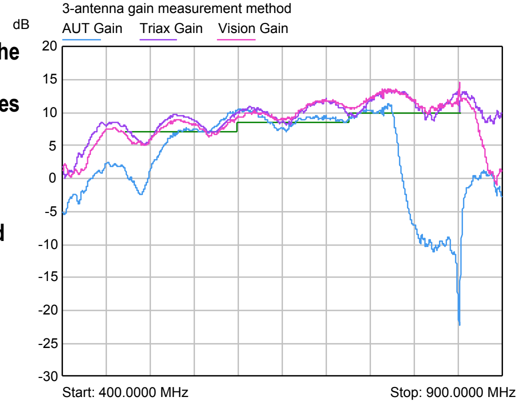
Raw Measurements

- Measurements every 5 degrees of rotation
- 6401 point sweep needed to sample S21 phase rotation due to long path length
- Ripple every 77.89 MHz due to ground reflection

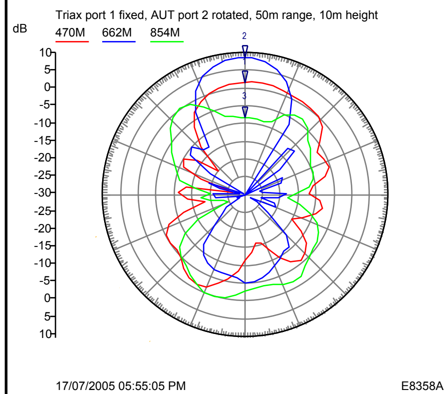


Calculated Results

- The results of the 3-antenna method produces results for all three antennas, assuming the measurements were conducted in free space



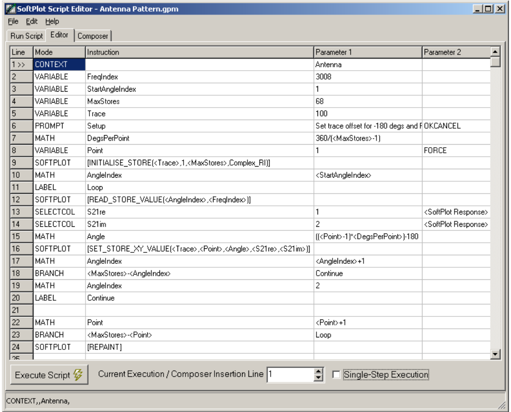
Directivity Measurements



Mkr	Trace	X-Axis	Value
1 ∇	470M	0 deg	1.43 dB
2 ∇	662M	0 deg	8.56 dB
3 ∇	854M	0 deg	-8.40 dB

- The frequency response measurements at different rotations are sliced through to get all rotations at any given frequency, using a simple script

Antenna Plot Script



SoftPlot Script Editor - Antenna Pattern.gpm

File Edit Help

Run Script | Editor | Composer

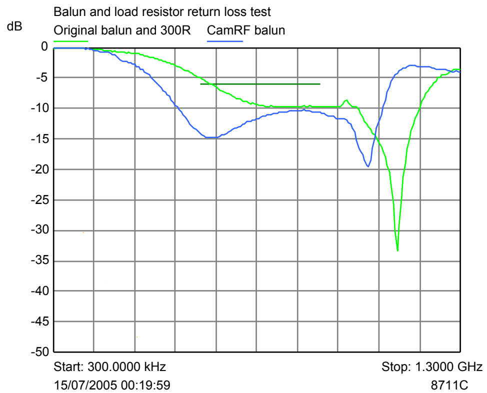
Line	Mode	Instruction	Parameter 1	Parameter 2
1 >>	CONTEXT		Antenna	
2	VARIABLE	FreqIndex	3008	
3	VARIABLE	StartAngleIndex	1	
4	VARIABLE	MaxStores	68	
5	VARIABLE	Trace	100	
6	PROMPT	Setup	Set trace offset for -180 degs and F	OKCANCEL
7	MATH	DegsPerPoint	360/(<MaxStores>-1)	
8	VARIABLE	Point	1	FORCE
9	SOFTPLOT	[INITIALISE_STORE(<Trace>,1,<MaxStores>,Complex_RI)]		
10	MATH	AngleIndex	<StartAngleIndex>	
11	LABEL	Loop		
12	SOFTPLOT	[READ_STORE_VALUE(<AngleIndex>,<FreqIndex>)]		
13	SELECTCOL	S21re	1	<SoftPlot Response>
14	SELECTCOL	S21im	2	<SoftPlot Response>
15	MATH	Angle	((<Point>-1)*<DegsPerPoint>)-180	
16	SOFTPLOT	[SET_STORE_XY_VALUE(<Trace>,<Point>,<Angle>,<S21re>,<S21im>)]		
17	MATH	AngleIndex	<AngleIndex>+1	
18	BRANCH	<MaxStores>-<AngleIndex>	Continue	
19	MATH	AngleIndex	2	
20	LABEL	Continue		
21				
22	MATH	Point	<Point>+1	
23	BRANCH	<MaxStores>-<Point>	Loop	
24	SOFTPLOT	[REPAINT]		

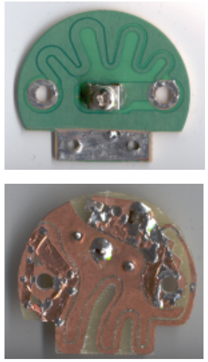
Execute Script | Current Execution / Composer Insertion Line 1 | Single-Step Execution

CONTEXT,,Antenna,

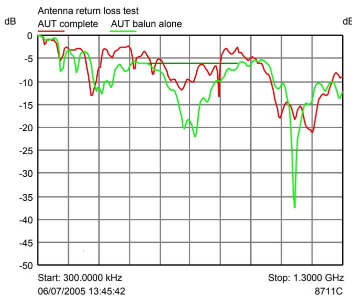
- Knowing how many measurements corresponded to a full 360 degrees allows the measurements to be apportioned equally
- Choose any frequency point to create an antenna plot from the existing data
- The same measurement set is used for directivity and gain

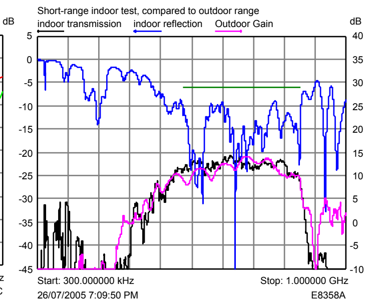
Balun Redesign





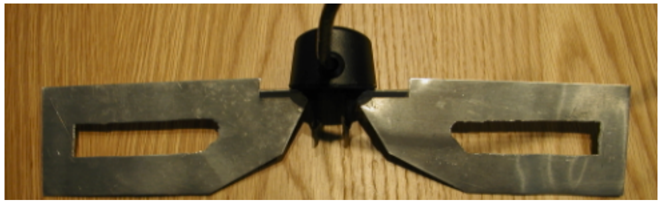
Diagnostic Measurements





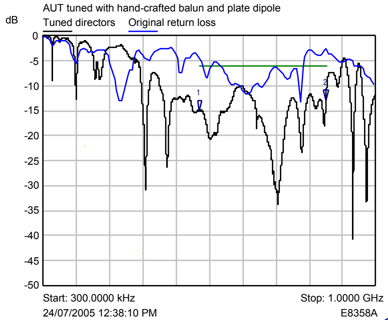
- Indoor Reflection measurements of complete antenna and of balun alone
- Indoor transmission measurements enable interactive testing, once a relation with the outdoor range is established

Dipole Redesign



- The original dipole didn't have a good response at the top of the band.

Return Loss Improvements



- Repositioning of directors to improve broadband match

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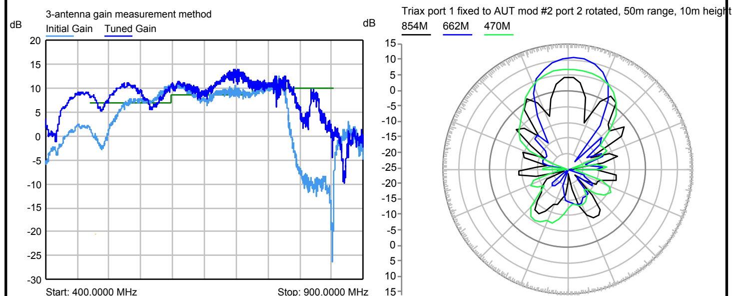
Gain and Directivity Re-measured



- Much better – but not good enough yet…

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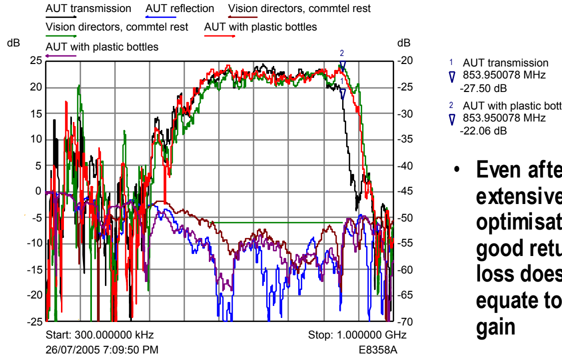
Hunting for the limiting factor



- Even after extensive optimisation, good return loss does not equate to high gain

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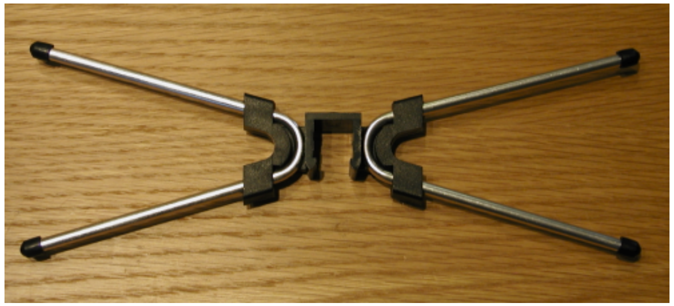
Lossy Plastic



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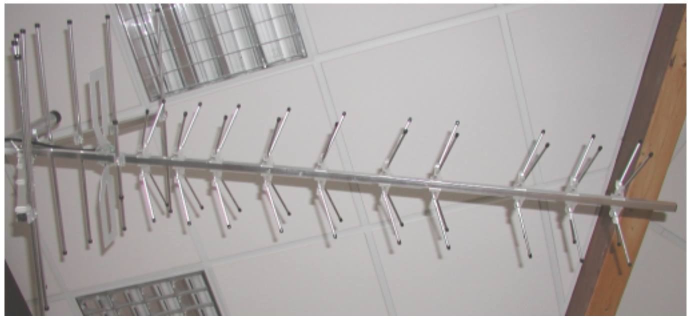
Prototyped using Available Plastic

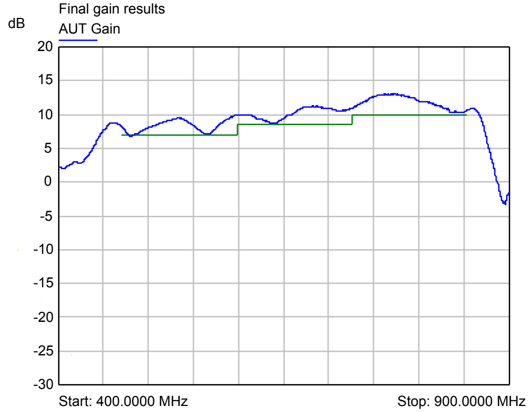
- The “Ten Green Bottles” Design
- Proves that the director plastic affected performance

Re-made using Clear Plastic

- Lack of black pigment improves loss, compensate for dielectric constant by angling the directors forward



Final Results



Conclusions

- Antenna measurements can be made with a network analyzer and a field
  - *75 ohm calibration, 75 ohm cables, losses aren’t too great*
  - *Polar plots using Aerial rotator idea*
  - *Three-antenna method gives good results without needing a calibrated reference antenna*
- Indoor measurements are useful for diagnostics
- Real-world problems provide valuable experience
  - *Beware black plastic in wireless applications*