HF OPS

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THE YAGI ANTENNA

How does it “Work”

by

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VA7JW

May 2017

The Yagi Antenna

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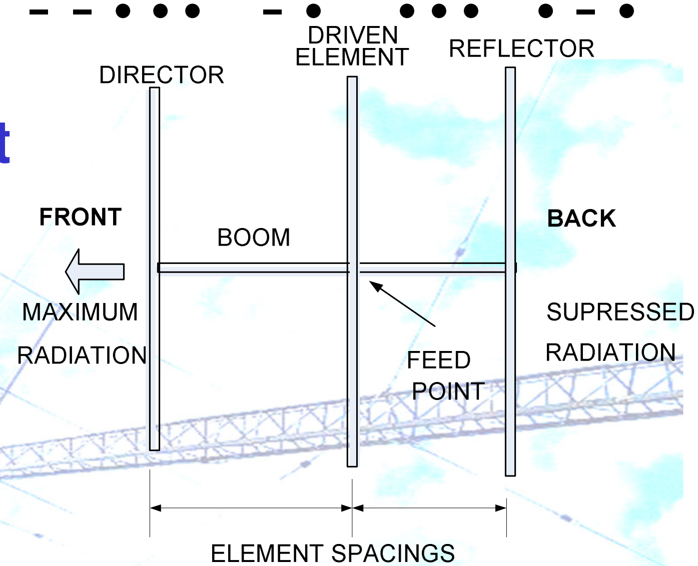
- One of the most popular and successful antennas developed for HF work is the Yagi antenna
- Because of the configuration of the antenna elements, the radiation pattern forms a “beam” thus concentrating and projecting a signal in a specific direction and reducing unwanted receive signals from all other directions.
- The Yagi is often referred to as a BEAM antenna

Antenna Elements

- Driven Element – Half wave resonant dipole with feed point



- Director – a passive element, slightly SHORTER than Driven element – Forward direction
- Reflector – a passive element, slightly LONGER than Driven Element, is Back of beam
- Boom is the mechanical support
- Length & spacing of elements important parameter

Driven (DRV) Element

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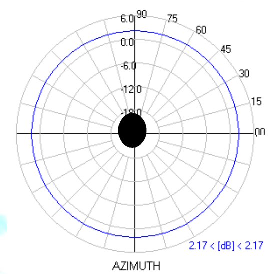
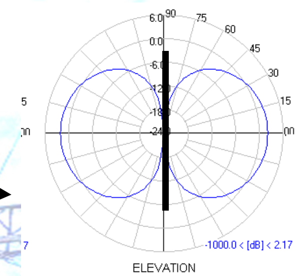
- DRV element acts like a dipole



  Radiates equally on axis

  - Max radiation off the side



- DRV element transmits and receives signal
- Half wavelength, resonant on band of operation
- Dipole feed point Z is ~ 70 ohms but proximity of other elements will lower feed point Z to ~ 20 ohms as elements are closely spaced, typically << 0.5λ

Director (DIR) Element

-.-. --.- -.. . ...- . --... -. ... .-.

- Passive, a conductor, typically either a rod or a tube known as a Parasitic element
- Mechanically bolted at its center, to the Boom. This is OK as the center is at a zero voltage point
- It is SHORTER than the driven element by about 5%
- DIR is typically 0.125 λ in front of DRV element, close coupled
- Being Shorter than the DRV element endows the antenna with an ability to focus the DRV element radiation in a Forward direction, thus providing Gain

Reflector (REF) Element

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- Passive, a conductor, typically either a rod or a tube. also a Parasitic element.
- It is LONGER than the DRV element by about 5%.
- REF is typically 0.25λ behind the DRV element, also close coupled
- Being Longer than the DRV element endows the antenna with the ability to 1) not only to suppress (unwanted) signals from the Back of the Beam, thus enhancing what is known as the Front to Back, F/B, Ratio but 2) to also "reflect" radiation back to the DRV enhancing the Forward direction gain as well.

The Boom

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- The Boom is typically an aluminum tube or pipe to provide mechanical support for the elements.
- The Boom is not engaged in the tuning of the antenna
- The passive elements DIR, REF, are connected to the Boom at their physical centers, the zero voltage point.
- The DRV element feed point is isolated from the boom and is the Active element
- As the antenna elements are perpendicular to the boom, there is no electrical interaction between the elements and the boom.

Performance

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- The Yagi is very versatile. it can be designed to ,
  - maximize Forward Gain = off the front of the antenna
  - minimize reception from the rear of the antenna
  - maximize Front to Back Ratio
  - maximize Wide-band SWR
- Can’t have everything; most commercial Yagi’s are a compromise between all parameters, depending on what you want …. best gain, best F/B, best wideband..
- Customizing a Yagi is a complicated process unless you conform to a proven, optimized design. Difficulty in verifying performance when making “tweaks”

Addition of Elements

- For very wide band performance, 2 driven elements can be installed close to each other on the boom for wider band SWR
- GAIN can be increased by adding more directors. Directors are more productive than Reflectors
- Front to Back, rejection of signals off back of antenna can be improved by adding a second Reflector
- Longer booms for wider spacing of elements can provide more Gain or F/B, but not both at same time

Multiband Yagi's ?

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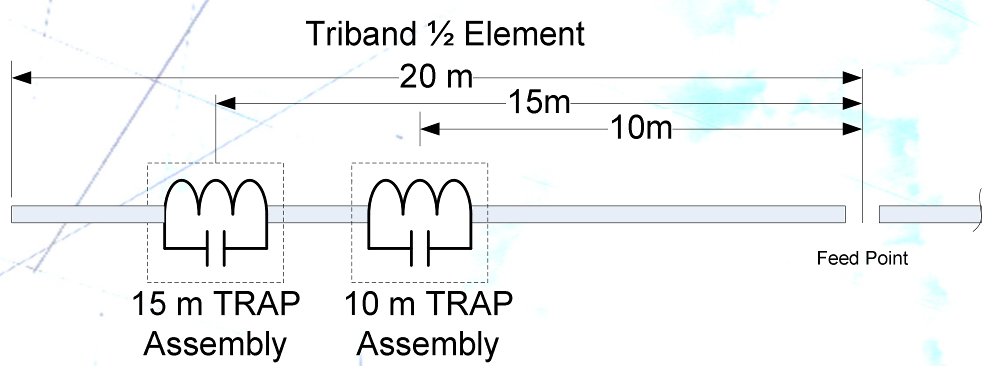
- So far, only the basic Single Band, i.e. Mono-Bander Yagi has been presented
- What if you want Multiband performance ?
- Typically 20, 15 and 10m operation, perhaps also 17 and 12 m.
- Most commonly, Tri-Band 20/15/10 Yagi's are offered.
- Referred to as a "Trap" antenna

The Tri-Band Yagi

- Typical 3 element 3 band 20/15/10 m operation
- Traps are shown, 4 on each element, 2 per side, 10m trap & 15m trap

- A Trap is a parallel resonant circuit that isolates element segments into 10m , 15m & 20 m segments
- Parallel resonant circuits go Hi Z & isolate sections



Log Periodic

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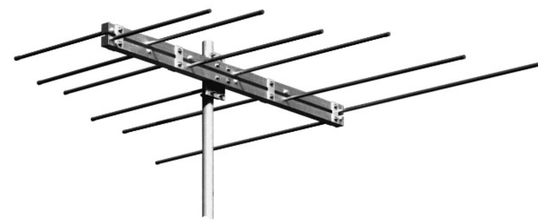
- A type of Yagi that has a number of highly tapered elements, 5 to 10
- Exhibits continuous gain over wide band widths, typ. 20 thru 10 m
- Can be viewed as having a 3 element yagi on all included bands, having a shorter element in front of the resonant element and a reflector at the rear.
- NSARC has an HF, 6 element log periodic



SteppIR

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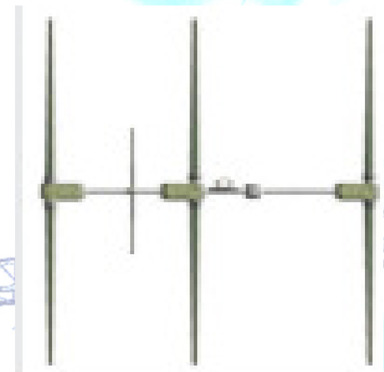
- Electromechanically adaptive element lengths.
- Copper tape elements are spooled in and out inside fiberglass tubes, driven by stepping motors



- Controller in shack monitors rig freq and commands motors to spool out correct tape lengths for each element independently always optimum, all frequencies, 20 thu' 6 m.

Beginnings - Jan 9, 1926

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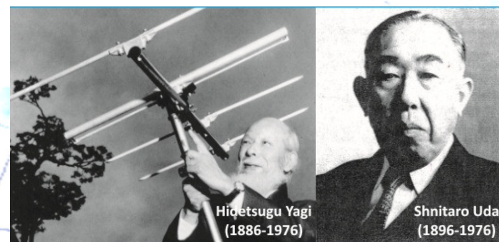
- Hidetsugu Yagi and Shintaro Uda at the Institute of Electrical Engineering, Tohoku Imperial University, Sendai Japan

Yagi



Uda

- Looking to find another way to focus radiation into a beam other than using a parabolic reflector
- Released their paper " Projector of the Sharpest Beam of Electric Waves"

The Concept

- Postulated that metal rods placed in front of or behind a radiating antenna may have directive or reflective properties
- Rod type elements overcome issues of Parabolic reflectors of size, weight, wind loading etc.
- Perhaps capable of forming a directional “beam” antenna
- Experiments took place at ~ 680 MHz (440 cm) and 750 MHz (400 cm)
- The following are excerpts from their original paper …

Reflector Elements

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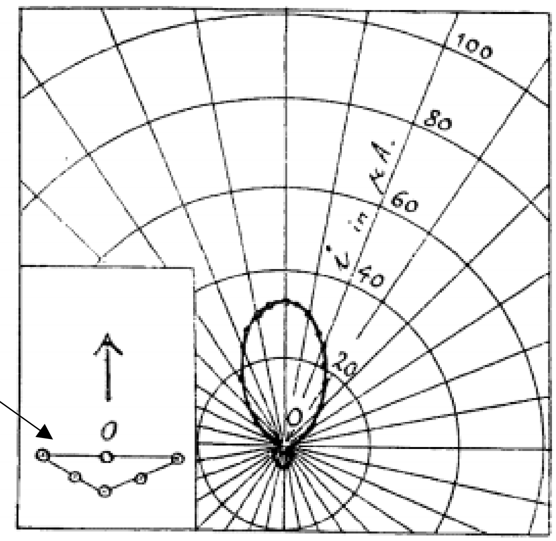
- Placed single wave reflector rod behind a resonant vertical driven element & found it had the effect of reflecting radiated energy forward.

- Developed screening rods to form a "Trigonal Director" for Transmitted signals and a "Trigonal Collector" for Receive signals.

Fig. 2.



Trigonal reflector with 5 rods.
Wave length = 440 cms.
Length of reflector rod = 220 cms.

- The Reflector principle was thereby established

Directors + Reflector

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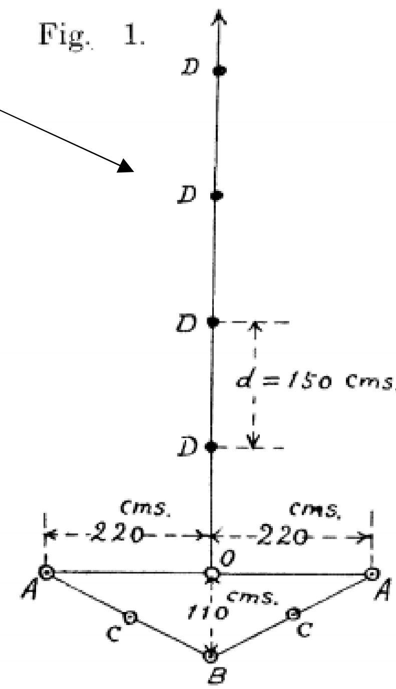
- “Using 4 rods “D” cut to ~ 82% of a hal wave, placed in-line, in front of the radiating element, “.. at equal intervals of about 0.34 wave length apart, the wave energy will be will be projected chiefly along this line.”



- “ .. the series of these wave directors forms what the authors called a Wave Duct or a Wave Canal”.
- The Director principle was thereby established

A Long Yagi – 3.7m

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- Per Fig. 4 text a combination of Trigonal Reflector + Wave Canal, at 750 MHz, consisted of 25 directors of 0.9 λ, spaced at 0.75 λ, produced a greatly increased receive signal level by a factor of 5 (over Fig 1)using a crystal detector and galvanometer.
- Gain = 20 log (150/30) ~ 14dB
- Required 25 Directors & 5 Reflectors
- Proved a point….

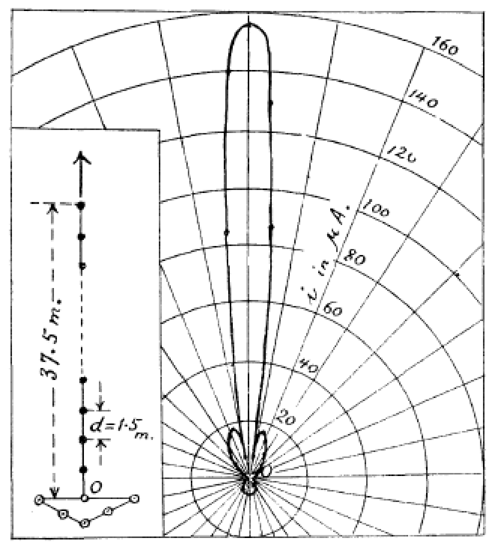

Fig. 4.

Wave projector.

Wave length = 400 cms.

◉ 5 rods, 220 cms. long

● 24 rods, 180 cms. long

What Yagi & Uda Knew

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Suppose that a vertical antenna is sending out electro magnetic wave in all directions around it. If a straight metallic rod of finite length be vertically erected within the field of its propagation, then the behavior of this metal rod will be as follows :—

When the length of this rod is equal to or slightly longer than a half wave length, the current induced in it will be in phase with or lagging behind the E.M.F. caused by the electric wave, and the rod will act as a "Wave reflector."

If, on the other hand, the length be made somewhat less than a half wave length, the current induced in it will be leading before the E. M. F., and the rod will act as a "Wave director".

Parasitic Element

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- In other words, this is what they knew ….
- Both DIR & REF elements have to be non-resonant
- The DIR is always Shorter acting as a SHORT antenna which has a Capacitive reactive component. Typically shortened ~ 5% to achieve an element inducing ~ 35 degrees of phase shift.
- The REF's is always longer acting as a LONG antenna which has a Inductive reactive component. Typically lengthened ~ 5% to achieve an element inducing ~ 35 degrees of (opposite) phase shift

Three Key Phenomena

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#1 PHASING. Realized that by altering the lengths of the passive, (parasitic) non-resonant, Director and Reflector elements, phase shifts would be introduced to a portion of the radiated signal due to their reactive component that would augment the wave radiated by the driven element, as it passed by.

#2 REFLECTION. Realized that a passive element would add a 180 degree phase shift to a portion of the radiated signal that would augment the wave radiated by the driven element, as it passed by.

#3 TRANSIT DELAY. Time it takes for the DRV wave to reach the DIR or REF element contributes to phasing

Phasing – Constructive / Destructive

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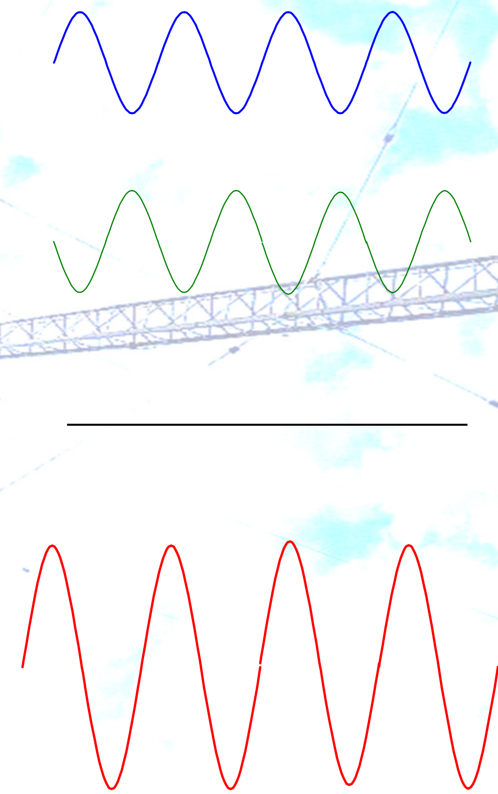
- Same Frequency, Same Amplitude

a) Reference phase 0 deg

b) 180 Deg out-of-phase

c) Addition of a+b
Cancels wave = Destructive

d) Addition of a+a, in-phase
Doubles amplitude = Constructive



Reflection

nsarc NORTH SHORE AMATEUR RADIO CLUB

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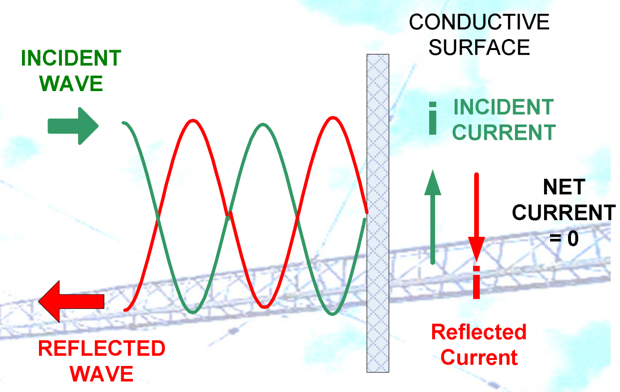
- Electromagnetic wave encounters conductive surface
- Green incident wave induces a current i in the conductor
- Assuming a perfect, conductor, resistance = zero = an infinite current must flow. Not possible.



- To make i = 0 an equal and opposite current i must flow which re- radiates the signal
- <u>Re-Emitted wave is 180 deg. out of phase (i.e think parasitic element function ….</u>

Transit Delay

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- Both the DIR and REF are spaced within ~ 0.1 to 0.5 λ of the DRV; spacing varies with design needs
- There is a transit delay of about ~ 45 deg. between the DRV and the DIR & REF elements
- This delay also contributes to the overall phase shifts
- Total delay between the DRV and the DIR is ~ 70 deg.
- These phase shifted waves all combine to produce a net forward wave that is now higher in amplitude than the wave emitted from the DRV element.

Antenna Capture Area

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- Capture Area refers to the ability of an antenna to extract energy from an electromagnetic wave.
- Represented as an area surrounding the antenna.
- Capture Area also referred to as Aperture.
- 20m dipole; ½ wave, ~ 32' long, #14 wire gauge, dia = 0.063 in.
- Physical area = 32 ft x .0052 ft = 0.166 sq ft
- Capture area is = $1.64\lambda^2/4\pi$ = 53 sq ft (λ = 64 ft at 20 m)
- Capture area (aperture) >> physical area by ~ x300
- Yagi elements are in near field and Capture Areas are very closely coupled, & focus energy easily

Director Phasing

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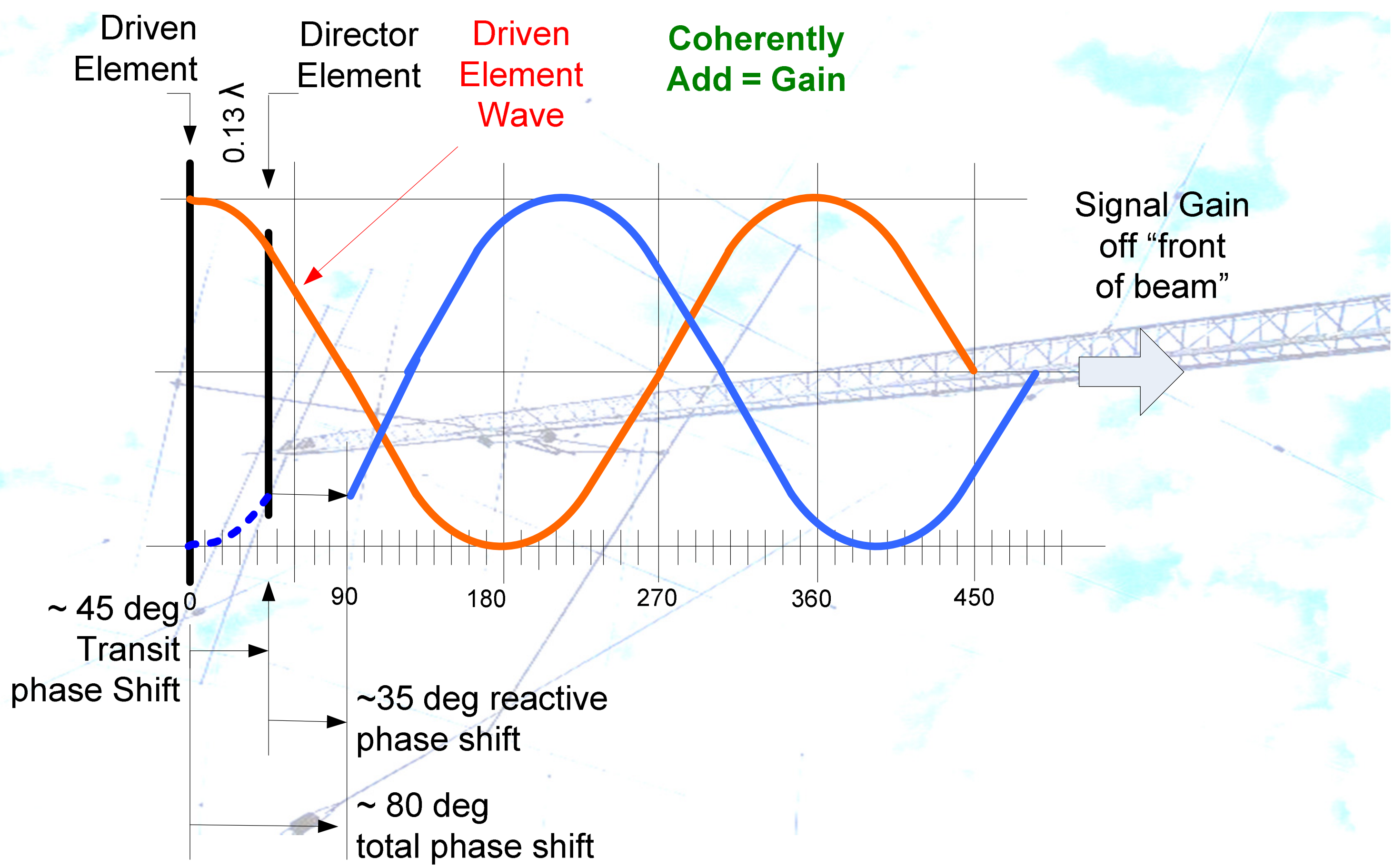
- The signal from the DRV element encounters the DIR element about 45 degrees later.
- At the same time, the DIR shifts the phase from part of the DRV signal by 180 deg as it passes by.
- The original signal from the DRV is now combined with a 45 degree transit + 35 degree phase shift
- The net result is a re-emitted signal from the DIR element that is shifted in favor of the original signal to produce an in-phase wave that combines coherently with the DRV signal = gain

Director Phasing



Reflector Phasing

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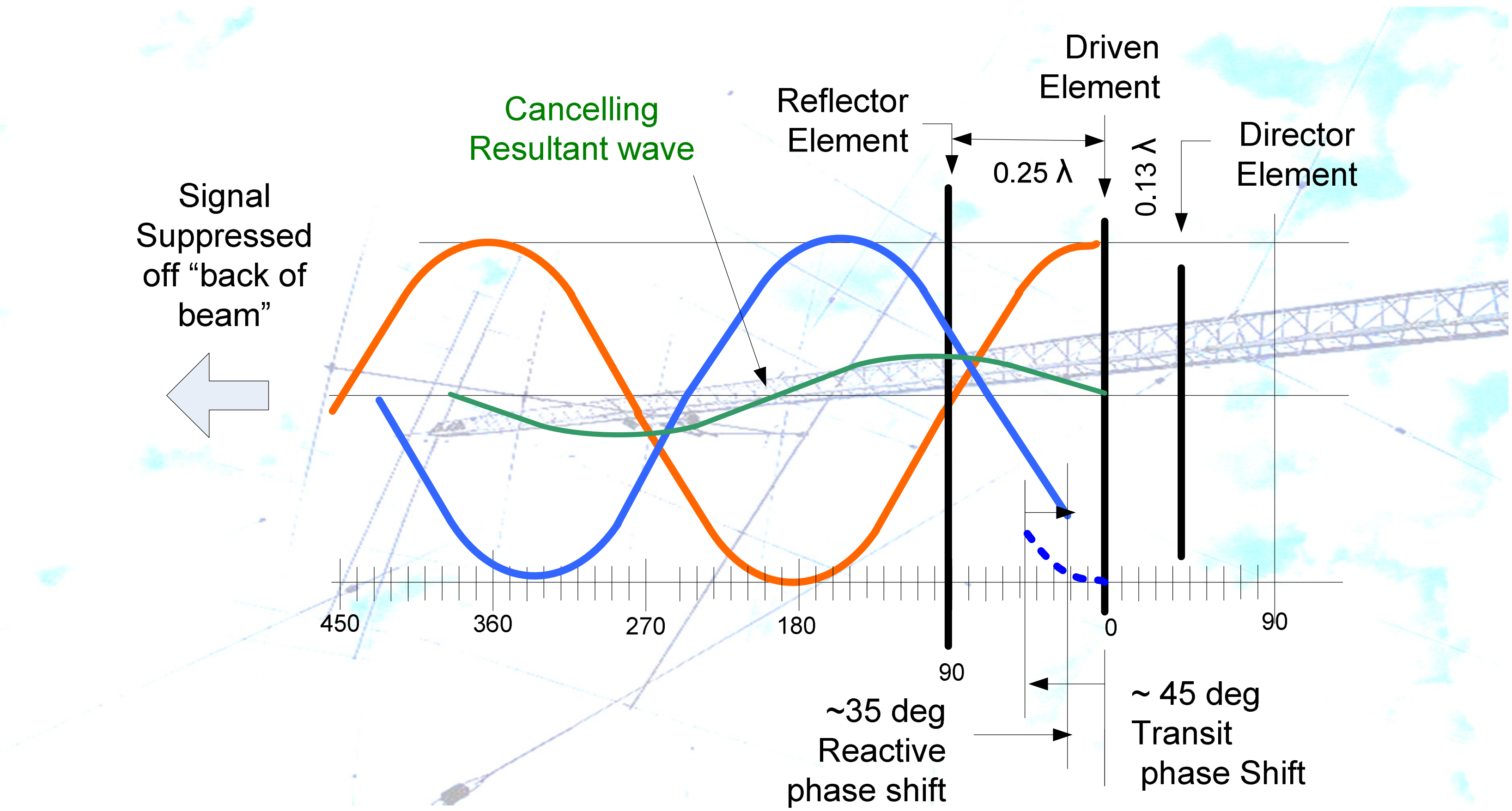
- The signal from the DRV element behind, encounters the REF element about 45 degrees later.
- At the same time, the REF shifts the phase from the DRV element by 180 deg as it passes by.
- The original signal from the DRV is now combined with a 45 degree transit -35 degree phase shift
- The net result is a re-emitted signal from the REF element that is shifted out of phase of the original signal to produce an out-of-phase wave that creates destructive interference with the DRV signal which suppresses signal off the rear of the antenna

Reflector Phasing



All Together Now …

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- The parasitic elements re-radiate the DRV wave
- The parasitic re-radiated wave is:
  - shifted 180 degrees due to reflection from the parasitic
  - shifted by a lesser degree due to inductive or capacitive action of longer (Reflector) or shorter (Director) lengths
  - Transit delay phasing
- Spacing between elements can vary the performance of the beam which can be adjusted for :
  - Maximizing gain at the expense of F/B
  - Maximizing F/B at the expense of gain

Animations of Phasing

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- **Phasing**

http://www.acs.psu.edu/drussell/Demos/superposition/interference.gif

- **Overview of a 3 element yagi phasing**
- http://www.radartutorial.eu/06.antennas/pic/YagiExplanation_gesamt.gif
- **Overview of 4 element yagi phasing**
- https://upload.wikimedia.org/wikipedia/commons/3/36/Yagi_antenna_animation_16_frame_1.6s.gif

Summary

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- **The YAGI is of simple mechanical construction that involves complex electrical phasing of the elements**
- **Very Effective.**
- **Many variations to suit. Tables, element schedules, spacing etc. on how to achieve your desired performance > ARRL antenna publications.**
- **Most simply buy to suit, not just performance, but Cost, Size, Weight, Wind loading, Tower, Rotors etc. have to be considered**
- **Now – What happened to Uda …**

Uda

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- The original concept of this antenna is attributed to Shintaro Uda in 1926
- Shintaro Uda was an Assistant Professor under Hidetsugu Yagi
- Hidetsugu Yagi, worked in the UK, USA and Germany, applied for patents on the new antenna both in Japan and the United States.
- While the Japanese patent was properly attributed to both the inventors, Yagi filed most successfully for the US patent.
- Courtesy The DX Zone