Coverage Range and Cost Comparison of Remote Antenna Unit Designs for In-building Radio over Fiber Technology

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Abstract. Future communication needs to be ubiquitous, broadband, convergent, and seamless. Radio over fiber (RoF) technology is one of the most important enabler in access network for the technologies. Adoption of RoF faces bottleneck in optoelectronics, that they are still expensive, high power consumption, and limited in bandwidth. To solve the problem, transceiver in remote antenna unit (RAU) is developed, i.e. electroabsorption transceiver (EAT) and asymmetric Fabry-Perot modulator (AFPM). This paper compares their coverage range and cost in providing WCDMA and WLAN services. Needed gain of RF amplifier for supporting picocell is also discussed.

Keywords: *optical transceiver; optoelectronics; picocell; radio over fiber; remote antenna unit; WCDMA; WLAN.*

1 Introduction

Future communication technologies are often called 4th Generation (4G), and characterized to be ubiquitous (anytime, anywhere, any device), broadband (sufficient data rate to deliver various services), convergence (support of various service types, data rate, and user), and seamless (always best connected, global roaming across wireless and mobile network) [1]. To meet these demands, there must be breakthrough in customer premise equipment (CPE), access network, as well as backhaul network. Access network and backhaul need to be cheap, flexible, scalable, upgradeable and programmable. One of the most important enabler for the access network is radio over fiber (RoF) technology. It locates remote antenna units (RAU) at needed places to serve customers and link the RAU to a central station (CS) via fiber optics. The RAU are designed to be simple, small, easy to install, almost maintenance free, and low cost. All signal processing, resources allocation, and other complexities are moved to CS. Figure 1 describes the basic block diagram of RoF.

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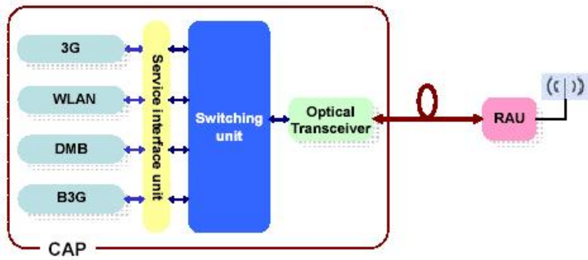

Figure 1 RoF system block diagram [1].

Beside for anticipating the future needs, RoF technologies has been deployed for cellular microcells and in-building picocells. ABI Research reported that in-building wireless systems markets will experience tremendous growth over the next five years. Deployments growth of this system has accelerated to 26%, and it is predicted that in 2013, more than 500,000 buildings will utilized in-building wireless system producing revenue around USD 13 billion [2]. Commercial buildings will become primary market for this system, in which large buildings (100,000 square feet or more) will choose distributed antenna system (DAS) and smaller building will use repeaters, femtocells, or picocells. RoF technology is capable to function as DAS, repeater, femtocell, and picocell.

However, RoF still faces some hurdles for being mass-adopted. Although RoF superior to coaxial in performance, it is only economical for distance larger than 100 m [3]. Optoelectronics components are still expensive, high power consumption [4], and also limited in bandwidth. To solve the problems, some optoelectronic transceivers have been developed: electroabsorption transceiver (EAT) [4-6], and asymmetric Fabry-Perot Modulator (AFPM) [7]. This paper summarizes the characteristics of EAT & AFPM, and compares their coverage range and cost in providing WCDMA and WLAN services. Needed gain of RF amplifier for supporting picocell with up to 100 m coverage is also discussed.

2 Optoelectronic Transceiver Characteristics

Optoelectronics play vital role in RoF system. It convert electrical signal to photonic signal and vice versa. Commonly, laser diode is used to convey data carrying RF signal into modulated optical signal, also known as optical modulator. The reverse process is handled by photodiode, as optical demodulator. Newly developed optoelectronics that function as both optical modulator and demodulator are commercial electroabsorption modulator (EAM), electroabsorption transceiver (EAT), optimized EAT, and asymmetric Fabry-Perot modulator (AFPM).

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2.1 Electroabsorption Modulator

Electroabsorption modulator (EAM) used to externally modulate light emitted by laser diode. However, it also can function as photodetector. Commercial EAM has been measured to determine its modulator and photodetector characteristics [8]. Because it is formerly intended for modulator, only one RF connector available at its package. Therefore, uplink and downlink signal must be separated by electrical circuit outside EAM. Package and picture of EAM is described in Figure 2.

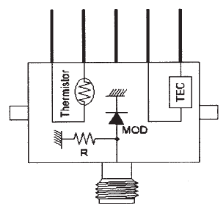

Figure 2 Package diagram of EAM module [9].

GANDALF has been measured commercial EAM produced by OKI (part number: OM5642W-30G) [8]. Lowest transmission loss was 5.5 dB at 0V. Polarization dispersion loss (PLD) was measured to be 0.5 dB. Measurement was conducted at biased voltage of 1.2 V. Bandwidth of this modulator was 34 GHz. Using wavelength of 1550 nm and photodiode of 0.85A/W responsivity (most commercial photodiode's responsivity is 0.7 A/W), it was found that modulator did not show saturation, and RF gain was about -53 dB when RF input power was 0 dBm. Photodetection measurement with 100% modulation and 0 dBm optical signal found that RF gain was -55 dB.

2.2 Electroabsorption Transceiver

Specially designed electroabsorption transceiver (EAT) has two RF ports, one port for uplink and the other port for downlink. Microwave Photonics, Inc. has been fabricated the device as depicted in Figure 3 [10]. Optical insertion loss was 5 dB, and when reverse biased at 5 V gave extinction ratio of 30 dB and responsivity of 0.9 A/W. Modulator and photodetector bandwidth at reversed bias of 2 V was more than 10 GHz. RF loss for downlink path at optical input power of 5 dBm was 35 dB, and slope of -2 dB per dBm optical input. The downlink RF loss curve was obtained with high RF input power (15 – 20 dBm), frequency 2.5 GHz, and reversed bias was 2 V. RF input power of 17 dBm produced modulation depth of 70%. Uplink needs low RF input power (< 0 dBm). With RF input power of 0 dBm and reversed bias voltage of 0 V, RF insertion loss (IL) was 39 dB at optical input power of 5dBm. Figure 4 shows uplink loss slope -1.6 dB per dBm optical input power [5].

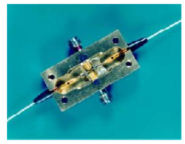

Figure 3 Prototype transceiver (EAT) unit developed by BTexact [10].

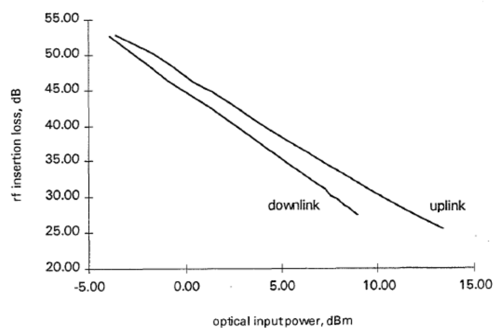

Figure 4 Downlink and uplink loss as function of optical input power [5].

2.3 Optimized EAT

EAT is still possible to be optimized to obtain certain goal. Hur *et al.*[6] conducted a simulation to balance uplink and downlink gain by setting EAT's chip length to 400 um. At reverse bias voltage of 0 V, responsivity was 0.8 A/W, and transmission was 0.1. Using RF input signal with Gaussian shape and peak power of -7 dBm, and assuming photodetector with responsivity 1 A/W as receiver, downlink and uplink loss could be calculated as depicted in Figure 5. Typical photodetector has responsivity of 0.7 A/W, so the uplink loss must be added by 3 dB to be used in typical application.

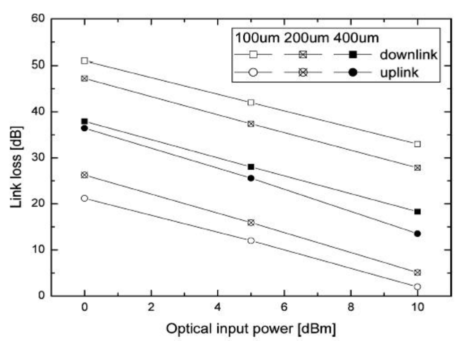

Figure 5 Calculated downlink and uplink loss vs. input optical power of the EAT for different chip length [6].

2.4 Asymmetric Fabry-Perot Modulator (AFPM)

An AFPM was fabricated using InGaAsP/InGaAsP multiple-quantum-well (MQW) and incorporating air-bridge to this modulator. At reverse bias of 3.4 V, responsivity was 0.28 A/W and modulation slope was 3.2 %/V. Optical insertion loss was 5 dB at 0 V bias. The new AFPM, as depicted in Figure 6, had RF modulation bandwidth of more than 15 GHz, and optical bandwidth of more than 17 nm [7]. With RF input power of 2 dBm, optical incident power of 0 dBm, and using commercial photodiode with responsivity of 0.7 A/W, uplink loss was 58 dB. Downlink loss of 49 dB was obtained when AFPM functioned as photodetector of optical signal from Mach-Zender Modulator (MZM) with 10 dBm RF input power and 10 dBm of optical input power [8].

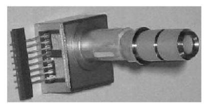

Figure 6 Packaged AFPM module [7].

3 Coverage Range Comparison

Indoor radio propagation is affected by layout in building, especially if the building is made from various materials. The transmitted signal reach the receiver via many paths, due to reflection, scattering, refraction, and diffraction by objects such as walls, floors, doors, and windows inside building. Path loss for indoor propagation must include wall attenuation factor (WAF) and floor attenuation factor (FAF), which are affected by the number of walls or floor traversed by the signal, and material of the walls and floor [11]. However, for generality and simplicity, this paper uses path loss model that average the wall factor, and assumes propagation at one floor. Power delay profile also must be considered, since it is related with bandwidth limitation of channel.

Motley and Keenan [12] reported the results of propagation experiments inside a multi-storey office block at 900 MHz and 1700 MHz. Power-distance law can be expressed as

$$P = P' + kF = S + 10n \log d \tag{1}$$

where P is total propagation loss (dB), P' is path loss after reduced by attenuation from floors traversed by signal, S is path loss at 1m from transmitter (dB), n is power law index, d is distance between transmitter and receiver (m), F represents the attenuation provided by each floor of the building, and k is the number of floor traversed.

If propagation loss is predicted for the same floor, then *P* = *P'*. At 900 MHz, measured value for *F* = 10 dB, *S* = 16 dB, and *n* = 4. At higher frequency of 1700 MHz, *F* = 16 dB, *S* = 21 dB, and *n* = 3.5. Measured *S* at 1700 MHz is 5 dB higher than at 900 MHz, and it is close to 20.log(1700/900) = 5.5 dB. Extending this fact, we can use Motley-Keenan formula for frequency above 1700MHz using the same *F* and *n* at 1700MHz, and adding *S* with 20.log(*f*/1700) where *f* is working frequency in MHz.

As WLAN commonly works on 20 MHz channel and WCDMA uses 5 MHz bandwidth, wideband channel model must be considered. According to measurement by Saleh and Valenzuela [13], the measured median value for rms delay spread (τ_{rms}) within rooms is 25 ns and maximum value of 50 ns. Poon and Ho [14] did measurement for office and townhouse indoor channel and found that rms delay spread is between 10 to 30 ns. Using the maximum value, coherence bandwidth $(B_c = 1/\tau_{rms})$ is 20 MHz. Therefore, indoor office and townhouse channel is flat as long as the wireless communication use bandwidth no more than 20 MHz, as the case with our two examples (1 Mbps WLAN at 2.4 GHz and 2048 kbps WCDMA at 2 GHz).

Schematic diagrams of passive picocell using EAT and AFPM are depicted in Figure 7 and 8, respectively. WLAN access point is connected to CS, and WLAN card is attached to laptop (as mobile station, MS). In order to be comparable with previous report [15], WLAN access point and WLAN card are assumed to have 17 dBm RF output power and sensitivity of -82 dBm (1 Mbps), antenna gain for RAU is 8 dBi and, and MS's antenna has gain of 2 dBi. Working at 2.4 GHz, *S* (path loss at distance of 1 m) for WLAN is 24 dB and propagation loss for 100 m is 94 dB.

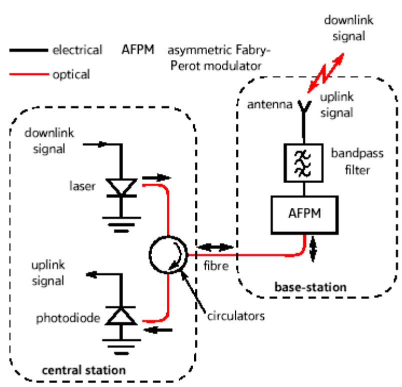

Figure 7 Passive picocell using AFPM [16].

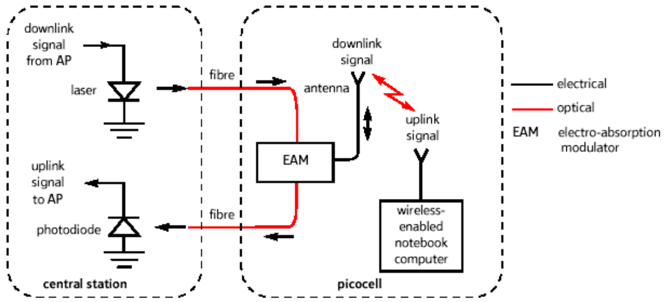

Figure 8 Passive picocell using EAT [16].

Table 1 shows coverage rage comparison of “passive” RAU design using 0V biased EAT (*EAT 0 V*), -2 V biased EAT (*EAT -2 V*), OKI’s EAM (*OKI*), optimized passive EAT (*Optim-EAT*), AFPM, and commercial laser diode (LD) and photodiode (PD) (*LD/PD*). Typical value for link loss of LD/PD is 39 dB [4]. Note that EAT 0 V, EAT -2 V, Optim-EAT, and AFPM have asymmetric range for uplink and downlink. In this case, coverage is determined by the shorter range at downlink or uplink. Therefore, EAT at 0V is predicted to provide coverage of 15 m, EAT biased at -2 V covers 12 m, OKI EAM only serves 7 m, PD/LD range is 21 m. Optimized passive EAT gives furthest range, i.e. 40 m; and AFPM provides shortest coverage, 6 m. There are wasteful ranges caused by asymmetric link budget. Hence, design of optoelectronics transceiver need to balance link loss for uplink and downlink. This requirement may not be needed in “active” picocell, as discussed in subsequent section.

Table 1 WLAN Coverage Comparison.

		EAT 0 V	EAT -2 V	OKI	Optim-EAT	AFPM	LD/PD
Uplink	Loss (dB)	39	47	55	29	58	39
	Power Margin (dB)	70	62	54	80	51	70
	Range (m)	**21**	**12**	**7**	**40**	**6**	**21**
Downlink	Loss (dB)	44	36	55	28	49	39
	Power Margin (dB)	65	73	54	81	60	70
	Range (m)	**15**	**25**	**7**	**43**	**11**	**21**

WCDMA transceivers at CS and MS are assumed to have the same values with WLAN, except sensitivity which is -103 dBm (2048 kbps) [10]. Propagation loss at 1 m for 2 GHz is 22 dB, and at 100 m is 92 dB. Table 2 tabulates the predicted coverage range. As with WLAN, AFPM gives the shortest range (26 m) and optimized passive EAT provides the furthest range (176 m). Asymmetric service range is also an issue here.

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Table 2 WCDMA Coverage Comparison.

		EAT 0 V	**EAT -2 V**	**OKI**	**Optim-EAT**	**AFPM**	**LD /PD**
Uplink	Loss (dB)	39	47	55	29	58	39
	Power Margin (dB)	91	83	75	101	72	91
	Range (m)	**91**	**54**	**32**	**176**	**26**	**91**
Downlink	Loss (dB)	44	36	55	28	49	39
	Power Margin (dB)	86	94	75	102	81	91
	Range (m)	**66**	**111**	**32**	**188**	**47**	**91**

4 RF Amplifier Gain for Picocell

Picocell has coverage range up to 100 m. To achieve this distance, the RAU needs to operate in active mode, by inserting RF amplifier between optoelectronic photodetector and antenna for downlink path, and inserting LNA between antenna and optoelectronic modulator. Table 1 and 2 show that WCDMA has longer distance than WLAN, because its sensitivity is much better than WLAN, and its path loss is smaller than WLAN. WLAN receiver sensitivity becomes range limiter; therefore, needed gain is calculated using WLAN, as shown in Table 3.

Table 3 Needed RF Amplifier Gain for 100m Picocell.

		EAT 0 V	**EAT -2 V**	**OKI**	**Optim-EAT**	**AFPM**	**LD/ PD**
Uplink	P_A (dBm)	-67	-67	-67	-67	-67	-67
	Optical Link Loss (dB)	39	47	55	29	58	39
	P_B (dBm)	-43	-35	-27	-53	-24	-43
	G_{LNA} (dB)	**24**	**32**	**40**	**14**	**43**	**24**
Downlink	P_{CS} (dBm)	17	17	17	17	17	17
	Optical Link Loss (dB)	44	36	55	28	49	39
	P_D (dBm)	-27	-19	-38	-11	-32	-22
	P_E (dBm)	10	10	10	10	10	10
	G_{PA} (dB)	**29**	**21**	**40**	**13**	**34**	**24**

RF amplifier calculation is based on block diagram in Figure 9. P_A is RF power at RAU antenna port (point "A"), received from mobile station (MS). To produce uplink signal power at CS to sensitivity level, P_A is amplified by LNA (G_{LNA}) to P_B level. P_B is power level at point "B," i.e. output of LNA and input of optical modulator. In downlink path, P_{CS} is output power from WLAN router. After attenuated by *Optical Link Loss*, the signal level becomes P_D at photodetector output. Ideal EIRP to cover 100 m range is P_E, and to provide this, the signal power level at antenna's input port should be P_{PA} ($P_{PA} = P_E - 8$ dBi). Needed gain of RFPA to amplify P_D to P_{PA} is G_{PA}. To ensure linearity, both RFPA and LNA are operated at 6 dB backoff from 1 dB compression point (P_{1dB}).

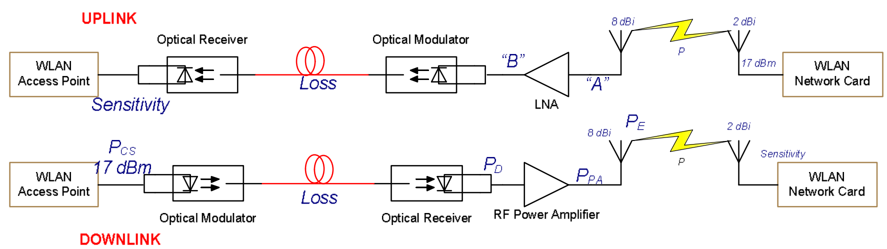

Figure 9 Block diagram for calculating RF amplifier and LNA gain.

Requirement for downlink RF amplifier gain for various optical transceivers and distances is described in Figure 10. P_{1dB} required for 100 m is 8 dBm, allowing low power and low cost amplifier to be used. Largest gain is required by OKI that need 40 dB for 100 m range. For uplink, LNA gain requirement is shown in Figure 11. P_{1dB} of the LNA is -18 dBm or less. Gain with zero value means that LNA or RFPA are not needed by the transceiver at that distance.

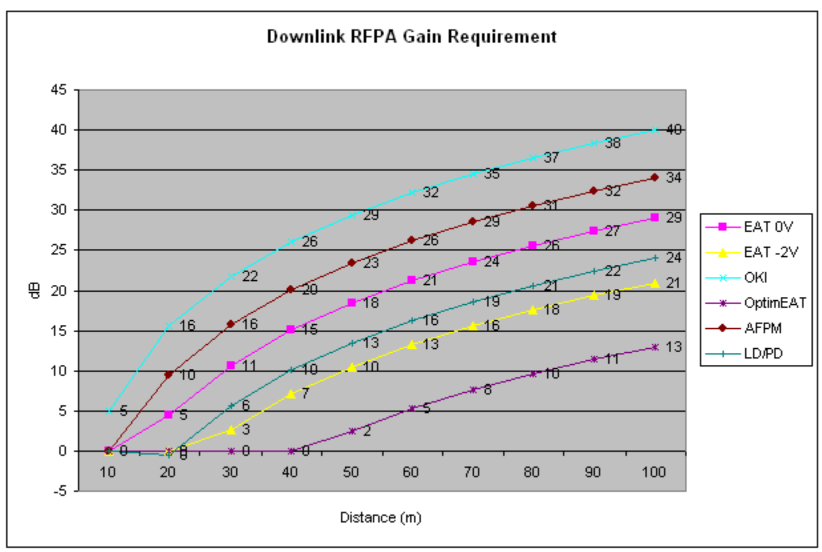

Figure 10 Downlink RF power amplifier gain requirement for WLAN.

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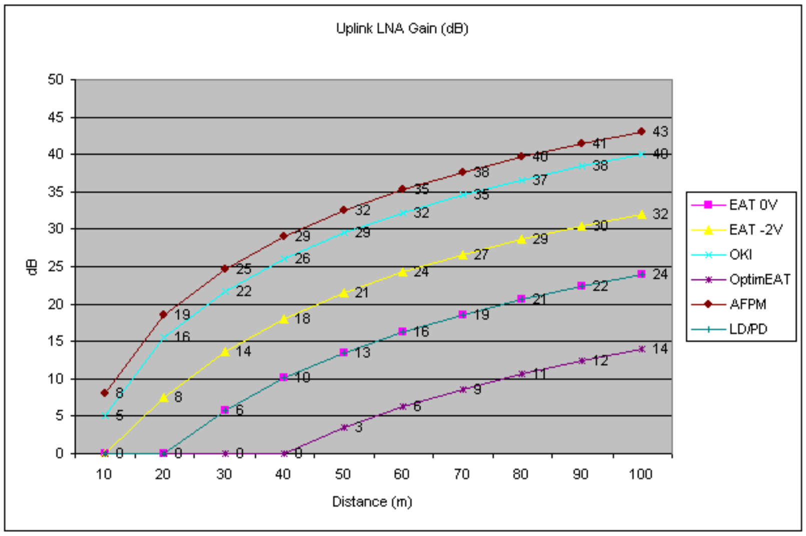

Figure 11 Uplink LNA gain requirement for WLAN.

5 Cost Comparison

Main-component cost of CS and RAU is shown in Table 4 [17]. CS of EAT-RAU consists of wideband directly modulated laser (DML) and wideband photodiode (WB-PD). EAT, OKI-EAM, and optimized EAT are assumed to have the same price. All CS have the same design, except CS for AFPM that use optical circulator to separate downlink and uplink optical signal from single optical fiber. Usually, EAT and LD/PD use two optical fibers, but single fiber can also be used if EAT is modified to reflective mode and LD/PD use different wavelength for downlink and uplink.

Major differentiator of cost is optoelectronics transceiver at RAU. EAT is very expensive due to packaging cost. EAT devices use very high confinement active layer to improve device efficiency, resulting in complex coupling procedure and optics type used. The cost is doubled since EAT has two optical port. To reduce the cost, the device must use waveguide modulator with one port operating in reflective mode [17]. AFPM has got this advantage, so that its cost is the cheapest.

To obtain needed coverage, RF amplifier must be inserted between optoelectronic transceiver and antenna at RAU. RF amplifiers models are products of Mini-Circuits [18]. The RF amplifiers considered in this paper are coaxial type that includes complete circuit (RFIC, passive circuit, PCB, connectors, and enclosure). The RFIC alone does not represent total price, because it is often cheaper than inductors, connectors, and enclosure.

Table 4 Component Cost of CS and RAU (USD).

EAT, Optim EAT, OKI EAM			
CS		**RAU**	
DML	911.25	EAT	3,869.10
WB-PD	1,215.00	Antenna	13.50
Subtotal	**2,126.25**	**Subtotal**	**3,882.60**
	TOTAL	**6,008.85**	
AFPM			
CS		**RAU**	
DML	911.25	AFPM	236.52
WB-PD	1,215.00	Antenna	13.50
Circulator	346.28		
Subtotal	**2,472.53**	**Subtotal**	**250.02**
	TOTAL	**2,722.55**	
LD/PD			
CS		**RAU**	
DML	911.25	DML	911.25
WB-PD	1,215.00	WB-PD	1,215.00
		Antenna	13.50
Subtotal	**2,126.25**	**Subtotal**	**2,139.75**
	TOTAL	**4,266.00**	

Among Mini-Circuits amplifier products that cover WCDMA and WLAN frequency (2.4 GHz) and fulfill P_{1dB} requirement, coaxial – low noise type is chosen as candidate for LNA and coaxial – wideband is chosen for RFPA. Scatter plot of WLAN LNA and RFPA prices versus gain is described in Figure 12 and 13. LNAs with the best gain-price ratio are ZX60-33LN-S+ (13.11 dB, USD 79.95), ZRL-2400LN (24.76 dB, USD 139.95), ZQL-2700MLNW (30.63 dB, USD 281.95), and ZHL-1724HLN (38.68 dB, USD 399.5). The LNAs are located at the bottom of gain-price scatter plot in Figure 12. RFPA with the best gain-price ratio are ZX60-3018G-S+ (19.66 dB, 40.95), ZX60-2522M-S+ (21.79 dB, USD 50.95), and ZX60-2534M-S+ (35.96 dB, USD 56.95). The RFPAs are located at the bottom of gain-price scatter plot in Figure 13.

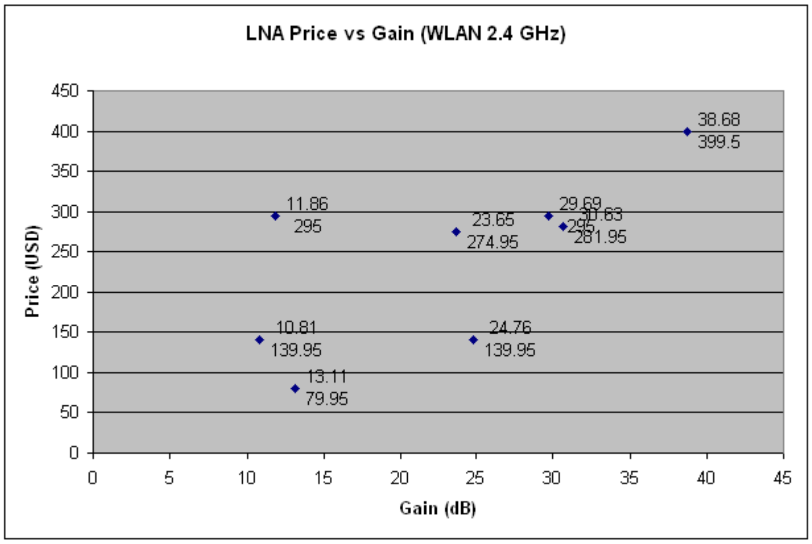

Figure 12 LNA prices vs. gain for WLAN 2.4 GHz.

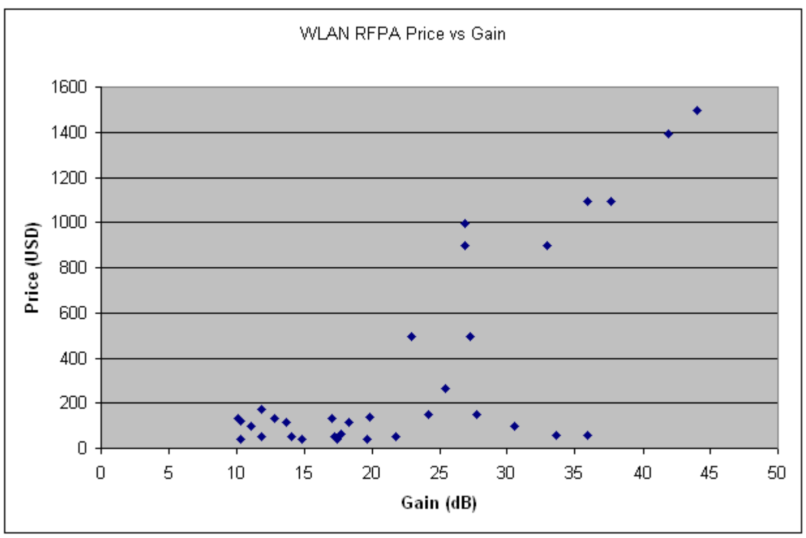

Figure 13 RF power amplifier prices vs. gain for WLAN 2.4 GHz.

As shown in Figure 12 and 13, LNA and RFPA are not available with gain in 1 dB increment. Otherwise, the gain value is discrete and almost random. Therefore, some required gain values are covered by LNA or RFPA which have

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the nearest, higher gain. As example, EAT 0V at 20 m downlink channel need 5 dB RFPA gain and covered by ZX60-3018G-S+ which has gain value of 19.66 dB. ZX60-33LN-S+ (13.11 dB) is used by Optimized EAT for uplink distance of 50 – 90 m.

RF amplifier costs versus distance are shown in Figure 14 and 15. It is noted here that gain value above 35.96 dB to 40 dB is covered by ZX60-3018G-S+ cascaded with ZX60-2534M-S+ as the case in downlink side of RAU using OKI. LNA with type of ZQL-2700MLNW is cascaded with ZX60-33LN-S+ to provide required gain for AFPM RAU for uplink distance of 80 – 100 m and OKI RAU at 100 m. Note that the price of the cascaded LNA is lower than ZHL-1724HLN (38.68 dB). Nevertheless, the cascaded LNA is not taking into account the price of matching circuit needed and the gain degradation caused by it.

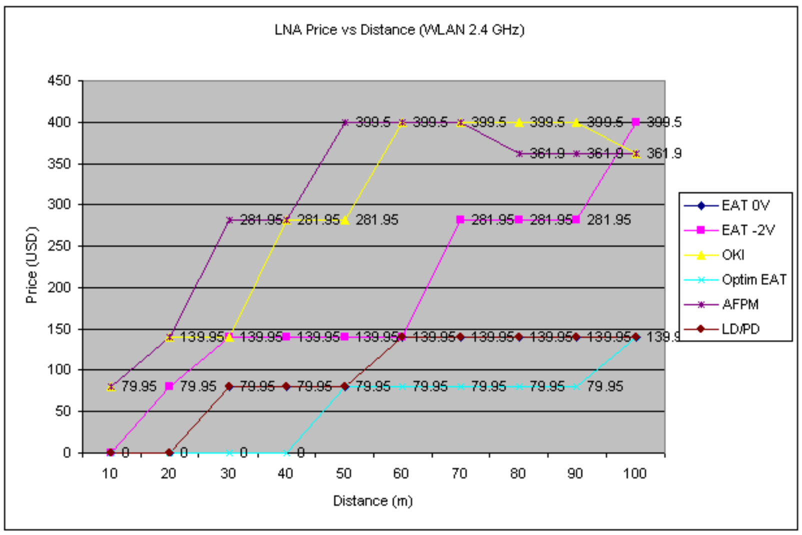

Figure 14 LNA price vs. distance for uplink channel of WLAN 2.4 GHz.

The combination of RFPA and LNA prices for each type of RAU for varied distances is described in Figure 16. Optimized EAT requires the lowest total amplifier cost, followed by LD/PD, EAT 0V, EAT -2V, AFPM, and OKI EAM. First factor to explain RF amplifier cost is link loss. OKI and AFPM need more expensive RF amplifiers since their link losses are high hence require higher gain RF amplifier. Second factor is commonly, LNA price is more expensive than RFPA which has the same gain and P_{1dB}. EAT -2V and AFPM have more link losses in uplink (around 10 dB), so that their LNA prices are much more expensive. Whereas, the RFPA prices of EAT -2V and AFPM are comparable with Optim-EAT, LD/PD, and EAT 0V.

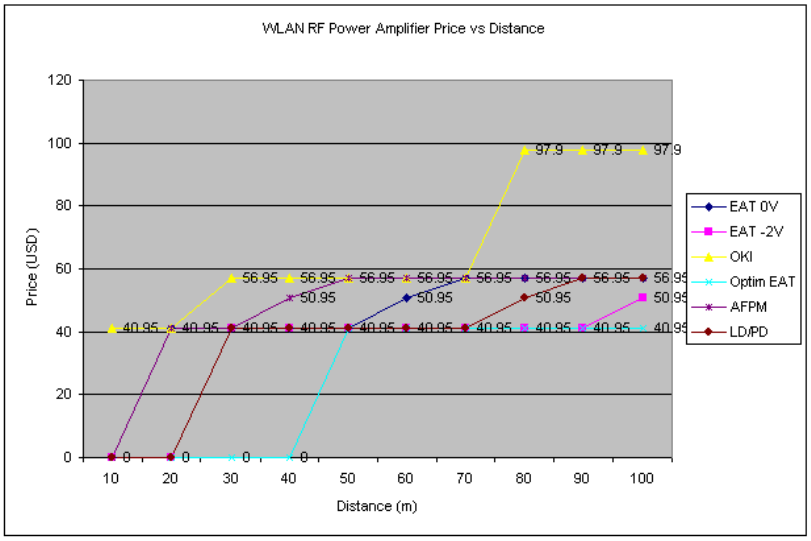

Figure 15 RF power amplifier price vs. service distance for downlink channel of WLAN 2.4 GHz.

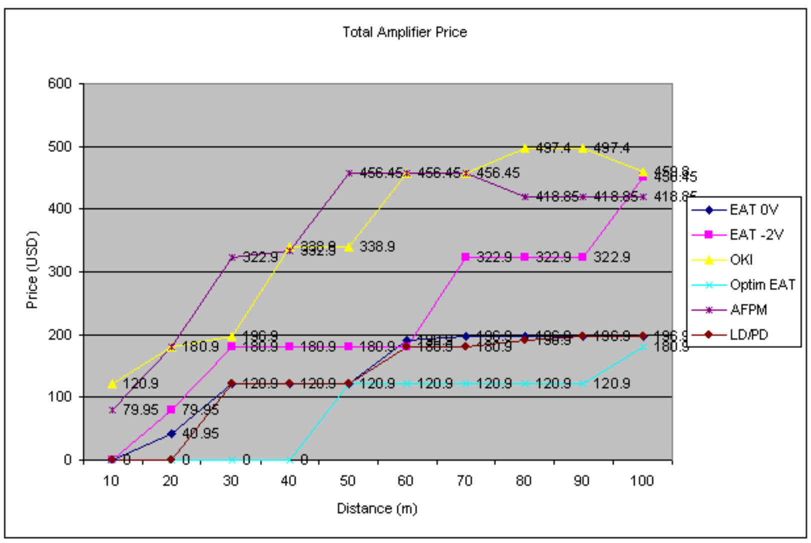

Figure 16 Total RF amplifier cost at each type of RAU vs. distance.

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Total cost consists of optical components and optoelectronics used in CS and RAU as listed in Table 4 added by total RF amplifier cost as mentioned in Figure 16. The result is described in Figure 17 and Table 5. As the optical components and optoelectronics become major part of the total cost, RF amplifier insertion to the RAU only increase the graph slightly. AFPM becomes the lowest cost, whereas LD/PD is the second. EAT 0V, EAT -2V, OKI, and Optimized EAT are forming clustered cost, since they are built from basically the same device.

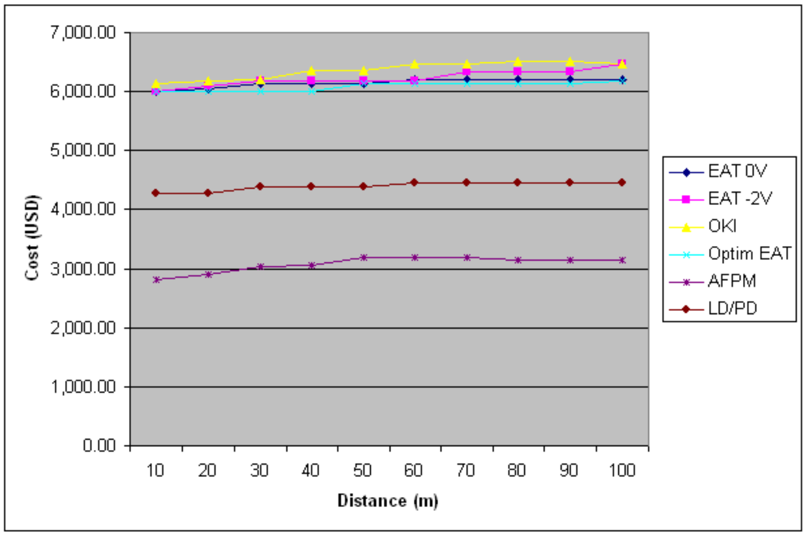

Figure 17 Total cost of CS and RAU (including optoelectronics and RF amplifier) vs. distance.

Table 5 Total cost (USD) of CS and RAU (including optoelectronics and RF amplifier) vs. distance.

Distance	10 m	20 m	30 m	40 m	50 m	60 m	70 m	80 m	90 m	100 m
EAT 0V	6,008.85	6,049.80	6,129.75	6,129.75	6,129.75	6,199.75	6,205.75	6,205.75	6,205.75	6,205.75
EAT -2V	6,008.85	6,088.80	6,189.75	6,189.75	6,189.75	6,189.75	6,331.75	6,331.75	6,331.75	6,459.30
OKI	6,129.75	6,189.75	6,205.75	6,347.75	6,347.75	6,465.30	6,465.30	6,506.25	6,506.25	6,468.65
Optim-EAT	6,008.85	6,008.85	6,008.85	6,008.85	6,129.75	6,129.75	6,129.75	6,129.75	6,129.75	6,189.75
AFPM	2,802.50	2,903.45	3,045.45	3,055.45	3,179.00	3,179.00	3,179.00	3,141.40	3,141.40	3,141.40
LD/PD	4,266.00	4,266.00	4,386.90	4,386.90	4,386.90	4,446.90	4,446.90	4,456.90	4,462.90	4,462.90

6 Discussion

Optical components and optoelectronics become major portion of RoF cost, although the systems use optoelectronics transceiver. Cost portion from additional RF amplifier is marginal because picocells require low power and therefore lower cost RF amplifier. As comparison, high power amplifier's price can reach USD 3,000 [15]. Hence, cost reduction of optoelectronics transceiver while maintaining good optical link loss is still an issue in picocell RoF system.

AFPM is the cheapest transceiver, and although it needs optical circulator at CS and require more expensive RF amplifier, the total cost is still the cheapest. Cost reduction offered by AFPM is significant, and can overcome additional cost of higher gain RF amplifier. But, to the authors' knowledge, there is no report of AFPM operated at 0 V bias to form truly passive picocell. However, cost reduction and simplification offered by AFPM can overcome power supply cost, since power line can be found easily in every building.

EAT is the most expensive, but still very attractive due to its ability to serve up to 40 m coverage range at 0V bias to create truly passive picocell. In voltage biased RAU, EAT as well as AFPM offer low power consumption, therefore its operational cost can be comparable with LD/PD which consume high power [4].

It is important to balance optoelectronics transceiver's link loss in passive picocell. However, active picocells use RF amplifier that has asymmetric cost in uplink and downlink. LNA used in uplink is more expensive than RFPA used in downlink. Therefore, uplink loss should be lower than downlink loss. Design of optoelectronics transceiver in active picocell should be optimized to overcome this problem. One indication of success of this approach is EAT 0V which has uplink loss that is 5 dB lower than its downlink loss. EAT 0V total RF amplifier cost is just USD 196.9, much lower than EAT -2V which require USD 450.45 for its RFPA and LNA to serve 100 m coverage. EAT -2V has uplink loss that is 11 dB higher than its downlink loss.

Optoelectronics transceivers operated in passive mode may be provide acceptable service range for certain application. Due to RF amplifier cost marginality compared with optoelectronics prices, operation in active mode is preferable to maximize coverage range in picocell.

7 Conclusion and Further Works

Coverage range and cost comparison of RoF system using EAT, AFPM, and LD/PD has been presented. The calculation is only based on power budget. Actually, noise, intermodulation, and other kind of nonlinearities should be taken into account (noise budget). AFPM potentially provides the cheapest solution if its photodetection efficiency can be increased. Further cost reduction to AFPM solution can be done by employing low cost laser emitter (VCSEL) and cheaper fiber such as multimode fiber (MMF). Nevertheless, AFPM has to be redesigned to work at 850 nm, or the VCSEL must be designed for 1.3 and 1.5 *u*m application.

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